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FOOD AVAILABILITY, FOOD HABITS, AND GROWTH OF TAHOE SUCKER, *CATOSTOMUS TAHOENSIS*, FROM A RESERVOIR AND A NATURAL LAKE[1]

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The diet of the Tahoe sucker, *Catostomus tahoensis,* inhabiting Webber Lake, a natural lake, is compared to the diets of Tahoe sucker in Stampede Reservoir, an artificial lake. Populations of benthic invertebrates and macrophytes differed in abundance between lake and reservoir. These differences had a substantial effect on the food habits of Tahoe sucker. The most important food items for lake suckers, mollusks and amphipods, were rarely found in the reservoir, and represented less than 1% of the total diet of reservoir suckers. Reservoir fish fed predominantly on macroalgae (43% by volume) and chironomid larvae (36%) and exhibited a less diverse diet than lake fish. Suckers beyond age I grew faster in Stampede Reservoir than in Webber Lake.

INTRODUCTION

Reservoirs and natural lakes differ in many limnological characteristics. Lakes are predominantly basin-shaped (resulting from glacial, volcanic, or tectonic activity), they discharge water from the epilimnion, retain nutrients, and dissipate heat (Wetzel 1975). In contrast, reservoirs are not basin-shaped, often discharge water from the hypolimnion, dissipate nutrients, and retain heat (Martin and Arneson 1978). These unique properties of artificial lakes affect nutrient cycling, sedimentation, mixing, and overall productivity (Neel 1967; Hannan, Young and Mayhew 1972; Mitchell 1973; Glymph 1973; Baxter 1977). Reservoir siltation often results in planktonic organisms forming the food chain base because benthic invertebrates are unable to survive (Isom 1971). Reservoir drawdown reduces the benthic fauna of the litteral zone (Hynes 1961, Lindstrom 1973), which further limits the foods available to benthic-feeding fishes.

The differences in food habits, food availability, and growth of the benthic feeding Tahoe sucker, *Catostomus tahoensis,* from Stampede Reservoir and Webber Lake, California, were studied. Stampede Reservoir (elevation 1794 m) is located about 25 km downstream from Webber Lake (elevation 2073 m) in the northern Sierra Nevada Mountains. Both waters are part of the little Truckee River drainage. Tahoe sucker are native to the drainage and are common in the reservoir and the lake. Because Tahoe sucker feed in the benthic zone (Marrin 1980) any differences in food availability between the reservoir and lake may affect food habits and growth of the sucker.

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[1] Accepted for publication October 1982

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METHODS

Fish were captured biweekly from July to October 1979, using fyke nets, wire mesh (1.2 cm) traps, or experimental gill nets (1 cm to 8 cm bar mesh). Nets and traps were set at three sampling stations in Webber Lake and at four stations in Stampede Reservoir. Each station was selected to represent a major habitat type (shallow, middepth, and deep water) as defined by Marrin (1983). Gill nets were set from dusk to dawn, while fyke nets and traps were set both day and night. Once captured, fish were iced to prevent regurgitation and decomposition of stomach contents. Each fish was dissected and the section of gut containing readily recognized food items (i.e., not broken or digested into unidentifiable fragments) was removed and fixed in 7% formalin. This procedure reduced the error associated with identifying differentially digested food items.

Macroinvertebrates were removed, counted, dried of excess formalin on a vacuum filter, and their volume determined by the displacement of water in calibrated test tubes. Macrophytes were measured only by volume displacement. The food items (percent volume) from reservoir fish were compared to food items taken from lake fish using the arcsin square root transformation of the t-test (Sokal and Rohlf 1969). Pectoral fin rays were removed from all suckers and cut into transverse sections for age analysis (Vondracek 1977). Age and growth data were based on back-calculated ages determined from these sections. Age and mean standard lengths (SL) from the back calculations were compared using a t-test (Sokal and Rohlf 1969).

Diving surveys were used to collect monthly core samples of benthic invertebrates. Cores were taken with a 4-cm diameter pipe driven 8 cm into the substrate. Eighty-eight cores were taken from Stampede Reservoir and 105 cores from Webber Lake. Samples were taken at the designated stations from three depth zones (1–2 m, 5–6 m, and 10 m). Core samples were transferred to plastic bottles underwater, brought to the surface, sieved (0.3 mm mesh), and preserved in 70% ethanol. Invertebrates were identified to family and counted under a dissecting microscope in the laboratory. Densities of benthic invertebrates from the lake and reservoir were compared using the Mann-Whitney U-test (Sokal and Rohlf 1969). General composition of the lake and reservoir bottoms was determined by viewing 0.5 m^2 quadrats located at 10 m intervals along 200 m transects. These transects ran parallel to shore at the three depth zones cited above. The amounts of exposed substrate, macroalgae, rooted aquatic vegetation, and submerged terrestrial plants were recorded while skin or SCUBA diving along these transects.

RESULTS

Similar benthic macroinvertebrate groups were found in the lake and reservoir, but mean seasonal densities of mollusks and oligochaetes from the reservoir and lake (Table 1) were significantly different ($P < 0.01$ and $P < 0.05$, respectively). Mollusks were more abundant in Webber Lake (mean 176/m^2) than in Stampede Reservoir (mean 28/m^2), while the reverse was true for oligochaetes (789/m^2 and 1308/m^2, respectively). The density of chironomid larvae was not significantly different between the two sites, but dipteran pupae were rarely sampled from the lake. Core sampling was not an accurate method to determine densities of the amphipod, *Gammarus lacustris,* because this animal is too mobile. *G. lacustris* was absent from benthic and gut samples from the reservoir but present in Webber Lake samples. *G. lacustris* inhabited weedy areas (*Anacharis canadensis* and *Ceratophyllum demersum*) in the lake. Aquatic plants (except for the filamentous green alga, *Rhizoclonium*) were scarce (12% bottom cover) in the littoral zone of the reservoir, but accounted for 57% of the bottom cover in Webber Lake (Table 1).

TABLE 1. Density of Macroinvertebrates and Bottom Composition in Webber Lake and Stampede Reservoir.

TAXA	*Stampede Reservoir (organisms/m² ± SD)*	*Webber Lake (organisms/m² ± SD)*
Chironomid larvae	1138 ± 363	867 ± 291
Dipteran pupae	17 ± 10	present
Mollusks	28 ± 18	176 ± 52
Oligochaetes	1308 ± 337	789 ± 256
BOTTOM COMPOSITION	(% Coverage)	(% Coverage)
Exposed substrate	52	43
Anacharis sp.	11	40
Rhizoclonium sp.	24	0
Other aquatic marcophytes	1	17
Terrestrial plants (dead)	12	0

The gut contents (aquatic macrophytes, mollusks, amphipods and chironomid larvae) differed significantly ($P < 0.05$) between reservoir and lake fish (Figure 1). Aquatic macrophytes and chironomid larvae were the most abundant food items for reservoir suckers, 43% and 36% by volume, respectively. These food items were less abundant among lake suckers, 4% and 17%, respectively. The lake population ingested a variety of aquatic plants (*Anacharis, Potamogeton* spp., *Ceratophyllum*), while the reservoir population ingested *Rhizoclonium* almost exclusively. Mollusks and amphipods were the major food items of lake suckers (29% and 20%, respectively), but together represent less than 1% of the total volume of food items from reservoir suckers.

Oligochaetes were abundant in the lake and reservoir but made up a small portion of the food items selected at either site. Willsrud (1966) noted that oligochaetes were not found in the gut of Tahoe sucker from Lake Tahoe, and suggested that oligochaetes may be ground up by pharyngeal teeth making them difficult to identify in gut samples. Lake and reservoir suckers ingested similar volumes of Cladocera, 10% and 9%, respectively. Cladocerans eaten were probably dead or had migrated to the bottom since only postlarval fish (which were not considered in this study) are limnetic feeders (Willsrud 1966).

Detritus and sediment ingested by Tahoe sucker amounted to approximately 42% of all material in the gut of both lake and reservoir fish. These values were not used when calculating the percent gut contents because the volume of detritus was equal in fish from both systems and because the nutritional importance of detritus to the Tahoe sucker is unknown.

Suckers captured in Webber Lake ranged in size from 65 to 270 mm (SL) while reservoir suckers ranged from 100 to 280 mm. The differences in size between lake and reservoir suckers were significant ($P < 0.02$) for all except age I fish. The slope of the length-age regression was 23.8 for reservoir fish compared to 16.1 for Webber Lake fish (Table 2). The estimated growth rate of fish from the lake was similar also to fish from the Little Truckee River and Sagehen Creek (Vondracek, Brown, and Cech 1982), the two sources of Stampede Reservoir (Table 2, Figure 2). The only other age and growth data available were from Lake Tahoe (north and south ends) and a tributary of Lake Tahoe, Burton Creek (Willsrud 1966). Mean fork lengths were adjusted to standard lengths by using factors cited in Carlander (1969) for other *Catostomus.* Comparison of all seven data sets (Table 2, Figure 2) shows fish from Stampede Reservoir attained a larger size from ages II to VII than any other population. Length-age regression equations were computed (Table 2). Equations computed from Willsrud (1966) are based on mean values of length (adjusted to SL) and age.

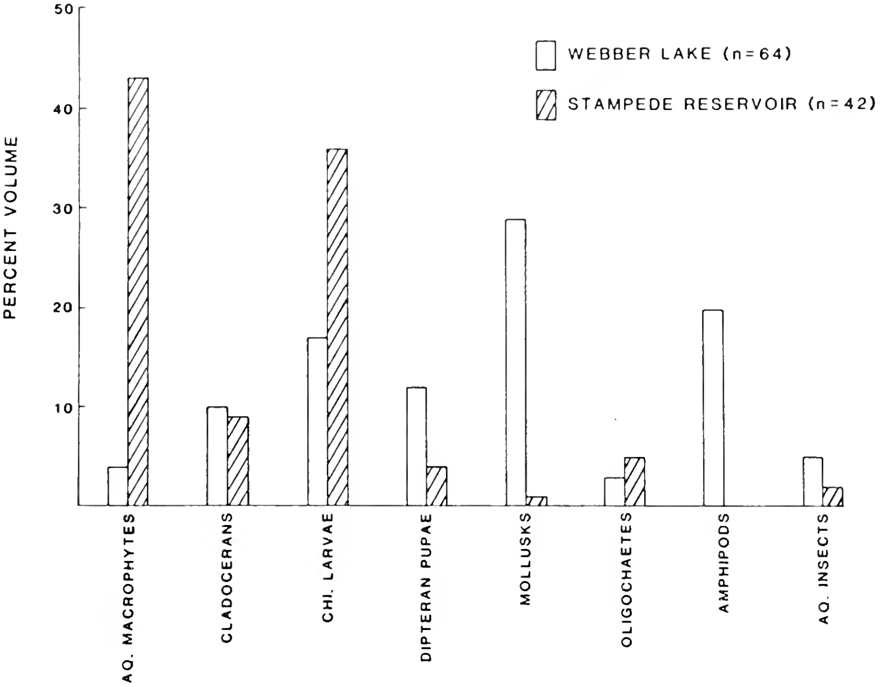

FIGURE 1. Percent volume of invertebrate foods of Tahoe sucker from Webber Lake and Stampede Reservoir. Data represent mean values from fish captured from July to October, 1979.

TABLE 2. Age-Length Regression Equations for Seven Populations of Tahoe Sucker.

System	*Equation*	*Source*
Webber Lake	SL = 51.9 + 16.14 AGE	This study
Stampede Reservoir	SL = 53.34 + 23.81 AGE	Vondracek *et al.* 1982
Sagehen Creek	SL = 53.58 + 16.71 AGE	Vondracek *et al.* 1982
Little Truckee River	SL = 44.53 + 17.31 AGE	Vondracek *et al.* 1982
North Shore Lake Tahoe[1]	SL = 10.5 + 27.1 AGE	Willsrud 1966
South Shore Lake Tahoe[1]	SL = 16.8 + 25.7 AGE	Willsrud 1966
Burton Creek[1]	SL = 23.4 + 21.9 AGE	Willsrud 1966

[1] Calculated from mean values of length and age after adjusting to standard length.

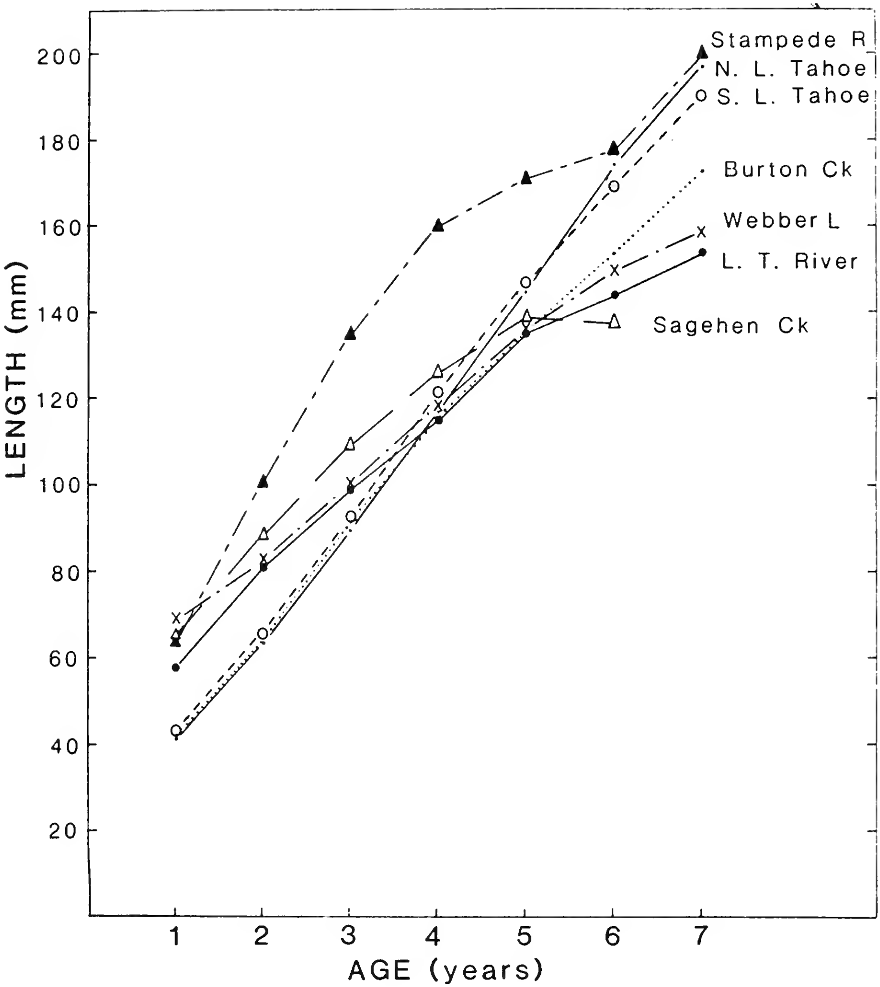

FIGURE 2. Mean back-calculated length and age of the Tahoe sucker in Webber Lake, Stampede Reservoir, Sagehen Creek, Little Truckee River, Lake Tahoe and Burton Creek. Data for Stampede Reservoir, Sagehen Creek and the Little Truckee River from Vondracek *et al.* (1982) and Lake Tahoe and Burton Creek from Willsrud (1966).

DISCUSSION

Stampede Reservoir is less diverse than Webber Lake in structure and composition of submerged vegetation as well as in composition of benthic invertebrates. Lindstrom (1973) noted that reservoir operations (particularly drawdown) limit the benthic fauna to especially tolerant organisms such as chironomids, and virtually eliminate rooted aquatic vegetation from the upper littoral zone. Stampede Reservoir has undergone wide fluctuations in volume since initial filling, particularly since 1975 following drought conditions (Marrin and Erman 1982). These differences in available food items between lake and reservoir are reflected in the diet of Tahoe sucker. Reservoir fish ingest fewer types of prey than lake fish because food items which are abundant in the natural area are absent or scarce in the reservoir. The Tahoe sucker is a generalist feeder and in Webber Lake where a variety of prey items are available, its diet reflects the relative abundance of benthic prey (Marrin 1983).

The greater amount of aquatic plant material ingested by reservoir than by lake populations suggests that reservoir fish either had a more omnivorous diet or coincidentally ingested *Rhizoclonium* while foraging for benthic invertebrates. Laboratory studies have shown that Tahoe sucker maintain their weight but do not grow on an entirely herbivorous diet (J. Cech and B. Vondracek, University of California, Davis, unpublished data); thus the overall value of plant food is uncertain.

Amphipods and mollusks were the most abundant food items in lake sucker guts but were absent or very rare in the gut of reservoir suckers. Chironomid larvae were the predominant invertebrate found in reservoir fish even though the density of chironomids did not differ significantly between the sites. In Lake Tahoe, Miller (1951) reported amphipods, mollusks, and chironomid larvae were the main food items of suckers. In Pyramid Lake, chironomids, amphipods and ostracods were the major invertebrate food items (Galat *et al.* 1981).

One effect of the difference in food availability between lake and reservoir suckers is on intraspecific partitioning of these resources. The types and quantities of food items consumed by all size classes of Tahoe suckers in Stampede Reservoir were similar; whereas, the diet differed among the same size classes in Webber Lake (Marrin 1983). Such circumstances could lead to lower growth rates in reservoir suckers if they were competing for limited food. However, comparison of available length-age data showed Tahoe suckers in Stampede Reservoir were significantly longer at ages from II and VII years than fish in Webber Lake, Sagehen Creek and the Little Truckee River (Vondracek *et al.* 1982). They were probably significantly longer than the three populations studied by Willsrud (1966) at least from ages II to V, but original data were unavailable to compute significance. Computed slopes from length-age linear regressions do not adequately reflect these differences in growth rate because the relationship for suckers in Stampede Reservoir is curvilinear.

Many factors may be responsible for the difference in growth rate between Webber Lake and Stampede Reservoir suckers. Webber Lake is higher in elevation and has slightly cooler temperatures than Stampede Reservoir (Marrin 1980). Also, differences in the nutritional value of detritus between lake and reservoir may influence growth, although the volume of detritus consumed by suckers was similar in both systems. Erman (1973) had noted that after initial filling of Stampede Reservoir, sucker populations changed in two ways. Compared to 10 years of survey in Sagehen Creek prior to impoundment, suckers (primarily yearling) were the most abundant in the sections immediately above the reservoir and fish in the reservoir were larger on the average than fish captured from the stream. The unstable conditions and simplified benthic food web of Stampede Reservoir apprarently have produced a more energetically optimum situation for Tahoe suckers than more stable natural systems.

The significant point we infer from these results is that, in spite of a restricted diet (e.g., fewer available food types compared to lake suckers), and overlap in diet among different size classes, reservoir suckers are probably not limited by the quantity of available food. If the reservoir population were food limited, depressed growth rates should have been evident. By feeding on chironomid larvae (mostly large *Chironomus*), reservoir suckers maintain as high or higher growth rates as suckers feeding on the great variety of food items available in natural systems.

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NEW HOST RECORDS OF TICKS (ACARI: ARGASIDAE AND IXODIDAE) PARASITIZING WILDLIFE IN CALIFORNIA AND A CASE OF TICK PARALYSIS IN A DEER [1]

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A single species of argasid tick and 6 species of ixodid ticks are recorded for the first time from 5 species of vertebrates in California: *Ornithodoros parkeri* from a desert tortoise, *Gopherus agassizii; Dermacentor* sp., probably *hunteri,* from a woodrat, *Neotoma* sp.; *Ixodes sculptus* from a marten *Martes americana; I. neotomae,* from a gray fox, *Urocyon cinereoargenteus;* and *D. albipictus, D. occidentalis,* and *D. variabilis* from mountain lion, *Felis concolor.* The provisional determination of a *D. hunteri* nymph from a woodrat is notable because it is apparently the first record of a wild-caught immature of this tick. New geographical and seasonal distributional data for *Ixodes texanus* parasitizing martens are given. Another case of tick paralysis in a Columbian black-tailed deer, *Odocoileus hemionus columbianus,* attributable to bites of the Pacific Coast tick, *D. occidentalis,* is described.

INTRODUCTION

In California, various species of wildlife or livestock serve as hosts for 49 indigenous tick species, as well as for an array of tick-borne animal disease agents (e.g., bacteria, protozoa, rickettsiae, viruses), several of which are pathogenic for humans (Lane and Murray 1980). The hosts of some ticks occurring in California are poorly known, particularly those that are fed upon by immature ticks; indeed, the larvae of six, and the nymphs of two of the 20 autochthonous *Ixodes* species have not been described. Knowledge concerning the life history of a tick must be considered incomplete until it is known from all of its life stages, and the host spectrum for each stage has been elucidated. The purpose of this report is to document several new host records for ticks occurring in the state and to describe another case of tick paralysis in a deer caused by the Pacific Coast tick.

MATERIALS AND METHODS

All ticks were determined to species with the aid of unpublished keys kindly provided me by Drs. Deane P. Furman and Edmond C. Loomis, University of California. Material provisionally determined to species was then compared with previously determined specimens and/or published descriptions contained in the works of Cooley (1938) and Cooley and Kohls (1944, 1945). Selected specimens were sent to Dr. James E. Keirans, Rocky Mountain Laboratories, Hamilton, Montana, for confirmation.

The body of a paralyzed deer was thoroughly examined and all ticks found were removed with forceps. Detailed notes were made of its physical condition, signs, and time to recover following tick removal. The animal was kept in a sheep pen while recovering to avoid exposure to predators.

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[1] Accepted for publication February 1983.

RESULTS

Six species of ixodid ticks and a single species of argasid tick, *Ornithodoros parkeri,* were recorded for the first time from 5 species of vertebrates in California; viz. *O. parkeri* from a desert tortoise; *Dermacentor* sp. probably *hunteri* from a woodrat; *Ixodes sculptus* from a marten; *I. neotomae* from a gray fox; and *Dermacentor albipictus, D. occidentalis,* and *D. variabilis* from several mountain lions (Table 1). Miscellaneous state collection records of ticks that were associated previously with pine martens and mountain lions also are given (Table 1) because relatively little is known about ticks infesting these carnivores. The 10 collections of *Ixodes texanus* from martens captured in Nevada Co. demonstrate that both nymphs and adults are active during winter and summer. Too few collections of the other ticks were made to warrant any comments concerning their seasonal distributional patterns.

As summarized (Table 2), 175 ticks of two species were removed from a Columbian black-tailed deer that was suffering from paralysis at the University of California Sierra Foothill Range Field Station in Yuba Co. on 1 November 1980. Of these, 164 were adults of *D. occidentalis* and 11 were nymphs of the winter tick, *D. albipictus.* Twenty-one of the 80 *D. occidentalis* females appeared to be fully-engorged and all 11 *D. albipictus* nymphs had fed to repletion. Most *D. occidentalis* ticks were attached to the crown of the head between the ears, whereas nymphs of *D. albipictus* were attached on the neck.

The deer, a male fawn estimated to be approximately five months old, had been found in a recumbent position in a mixed woodland-grass/chaparral plant community on 31 October 1980. When I first observed it the next day it was paralyzed and breathing slowly and shallowly, but otherwise appeared to be in good physical condition. Light infestations of fleas and hippoboscid flies were noted in addition to the heavy tick infestation. Within two hours following removal of all ticks, the fawn seemed to be slightly improved, and within 14 hours the animal could not be found inside the sheep pen. Two days after tick removal, however, the fawn was observed running around inside the pen.

DISCUSSION

The collection of a *Dermacentor* sp. probably *hunteri* nymph from a woodrat, *Neotoma* sp., is notable because it is apparently the first wild-caught immature of this tick. Heretofore, *D. hunteri* adults have been recovered from bighorn sheep, *Ovis canadensis;* mule deer, *Odocoileus hemionus;* Nuttall's cottontail, *Sylvilagus nuttallii grangeri;* humans, vegetation, and soil from southwestern U.S.A. and Mexico, with most records from bighorn sheep (Williams 1976). Except for these few adult collections, what little is known about the life cycle of *D. hunteri* is based on laboratory observations (Brinton, Beck, and Allred 1965). Although the woodrat from which the nymph was removed was not determined to species, the only species of woodrat that reportedly occurs in the area of San Bernardino Co. where the specimen was found is the Desert Woodrat, *N. lepida* (Ingles 1965). Finally, the *D. hunteri* nymph was also examined by Drs. Keirans and Furman, who both concurred that it is probably *D. hunteri.* In the absence of a series of specimens though, this determination must be considered provisional because of the similarity of *D. hunteri* nymphs to those of *D. parumapertus,* a parasite principally of lagomorphs and rodents, that likewise occurs in southeastern California (Cooley 1938).

TABLE 1. Records of Argasid and Ixodid Ticks Collected from Wildlife Species in California, 1973, 1978–1981.

		Number						
Host	*Tick species*	*L*	*N*	♂	♀	*Locality*	*Collector*	*Date*
Reptilia								
Desert tortoise (*Gopherus agassizii*)	*Ornithodoros parkeri*	0	0	1	0	San Bernardino Co., Tortuga Mtns., N ½ Sec. 34, T12N R11E	L. Dobak	12 May 80
Mammalia								
Woodrat (*Neotoma* sp.)	*Dermacentor ?hunteri*	0	1	0	0	San Bernardino Co., Kelso Mtns., Sheep Tank Wash NE ¼ Sect. 19, T12N R12E	S. Dake	30 May 80
Marten (*Martes americana*)	*Ixodes texanus* *	0	0	0	1	Nevada Co., Univ. of Calif., Sagehen Creek Field Station, ca. 8.0–8.5 mi. N/NW Truckee	W. Zielinski	18 Jul 79
"	"	0	1	0	2	"	"	22 Jul 79
"	"	0	2	0	2	"	"	29 Jul 79
"	*I. sculptus*	0	1	0	1	"	"	"
"	*I. texanus*	0	1	0	0	"	"	4 Aug 79
"	"	0	1	0	0	"	"	17 Aug 79
"	"	0	0	0	6	"	"	19 Sep 79
"	"	0	3	0	13	"	"	1 Feb 80
"	"	0	0	0	1	"	"	5 Feb 80
"	"	0	0	0	2	"	"	11 Feb 80
"	"	0	1	0	3	"	"	1 Sep 80

TABLE 1. Records of Argasid and Ixodid Ticks Collected from Wildlife Species in California, 1973, 1978–1981—Continued.

Host	Tick species	Number				Locality	Collector	Date
		L	*N*	♂	♀			
Gray fox (*Urocyon cinereoargenteus*)	*D. variabilis* *	0	0	1	1	San Luis Obispo Co., Montano de Oro (Horse Pasture)	R. Leflore B. Tanner	22 Feb 80
	Ixodes neotomae	0	0	0	2			
	I. pacificus *	0	0	1	0			
Mountain Lion (*Felis concolor*)	*Dermacentor albipictus*	0	0	0	1	Santa Barbara Co., Presbyterian Church Camp, top of Refugio Pass Rd.	J. Layne	2 Feb 73
	I. pacificus *	0	0	8	6			
	I. pacificus	0	0	0	1	Santa Barbara Co., Upper Santa Ynez River (nr. Agua Caliente Canyon)	J. Storrer	5 Feb 78
	I. pacificus	0	0	0	1	Santa Barbara Co., Rancho San Fernando Rey (nr. Paradise Rd.)	J. Storrer	4 Jan 79
	D. occidentalis	0	0	1	0	Santa Barbara Co., west end of Cachuma Lake	J. Storrer	11 Jan 80
	I. pacificus	0	0	1	5 **			
	D. occidentalis	0	0	57	34	Santa Barbara Co., 15 mi. N.E. of Sisquoc	M. Small	29 May 81
	D. variabilis	0	0	19	10			
	I. pacificus	0	0	1	2			
	I. pacificus	0	0	0	2	Santa Barbara Co., New Cuyama, Caldera Canyon	L. Johnston	3 Dec 81

* Tick species that have been recorded previously from the indicated host.

** Determinations of 3 must be considered tentative because capituli were missing.

L=Larvae, N=Nymph, ♂=Male, ♀=Female.

TABLE 2. Ixodid Ticks Removed from Paralyzed Male Fawn (*Odocoileus hemionus columbianus*), University of California, Sierra Foothill Range Field Station, Yuba Co., 1 November 1980.

	No. of ticks *		
Tick species	*N*	*M*	*F*
Dermacentor albipictus	11**	—	—
Dermacentor occidentalis	—	84	80***

* N = nymph, M = male, F = female.
** All engorged.
*** 21 engorged and 8 nearly engorged.

The desert tortoise previously has been recorded as a host of *Ornithodoros parkeri* in Utah (Edmunds 1951), but there have been no records of *O. parkeri* from this host in California until the present study. However, a closely related and morphologically similar tick, *O. turicata,* reportedly was obtained from desert tortoises in Thermal, Riverside Co., California (Harbison 1937).

Ixodes texanus is found most often on mustelids in the western U.S.A. and on raccoons, *Procyon lotor,* in the East (Keirans and Clifford 1978). It has also been collected from various species of lagomorphs, marsupials, and rodents. Adults and/or nymphs of this tick have been taken from martens before in California, Idaho, and Montana, but 8 of 10 such collections were made during the winter and the remainder in very early spring (Darsie and Anastos 1957). Records presented herein indicate that *I. texanus* adults and nymphs are active during summertime too; 7 of the 10 collections from Nevada Co. were obtained from July to September. The two previously published records of *I. texanus* from martens in California were from animals taken in the vicinity of Lake Tahoe in El Dorado Co. during winter (Darsie and Anastos 1957).

Ixodes sculptus, the only other tick found on the martens from Nevada Co., is widespread in western U.S.A. where it is frequently found on burrowing mammals or in their burrows or nests (Keirans and Clifford 1978). In California, ground squirrels, *Spermophilus* (formerly *Citellus*) spp., appear to be particularly important as hosts for both nymphs and adults of this tick (Cooley and Kohls 1945). The two specimens listed in Table 1 were obtained from a marten that was infested concurrently with *I. texanus.*

Well-documented cases of tick paralysis in four Columbian black-tailed deer from Calaveras, El Dorado, and Sacramento counties, and in a fawn from Fresno County, California, were attributed to *D. occidentalis* ticks by Brunetti (1965), although at least two of the animals were infested concurrently with *I. pacificus* adults. The possibility that *I. pacificus* may have been involved in some of these cases cannot be excluded since this tick has recently been incriminated as the cause of paralysis in a domestic dog (Nelson 1973) and a western harvest mouse (Botzler, Albrecht, and Schaefer 1980). Brunetti assumed that *I. pacificus* was not involved because no species of *Ixodes* had been known to produce paralysis in the U.S.A. Engorged female ticks removed from two of the deer included 59 *D. occidentalis* on a doe, and 39 *D. occidentalis* and 6 *I. pacificus* from a fawn.

The tick incriminated as the cause of paralysis in the present study was *D. occidentalis* since females of other ticks were not found on the animal. Tick paralysis is typically caused by the bite of females of certain tick species (Gregson 1973); males and immature stages normally do not produce this condition. Elsewhere in California, cattle and ponies have also suffered from paralysis following the attachment of *D. occidentalis* ticks (Parker, Brooks, and Marsh 1929; Emminger 1951; Brunetti 1965; Loomis and Bushnell 1968). Besides *D. occidentalis* and *I. pacificus,* the only other tick incriminated as a cause of paralysis in wildlife or livestock in the state has been the American dog tick, *D. variabilis* (Jessup 1979). Surprisingly, no human cases of tick paralysis have been documented in California even though the two most important ticks producing paralysis in humans in the U.S.A., namely, the Rocky Mountain wood tick, *Dermacentor andersoni,* and *D. variabilis* both occur here. According to Herms (1950), several mild cases of paralysis in children were reported to him in California, evidently as the result of attachment by *I. pacificus.* Unfortunately, Herms provided no supporting documentation to verify his statement.

A diagnosis of tick paralysis is confirmed when a paralyzed animal recovers after removal of one or more attached ticks. Most afflicted animals recover within a few hours to a few days if paralysis has not progressed too far. Brunetti (1965) noted that a doe and a fawn suffering from tick paralysis showed signs of recovery within 2–3 hours, and the doe was able to stand and walk, albeit unsteadily, within five hours after removal of ticks. Similarly, the fawn seen by me seemed improved within a few hours and had made at least a partial recovery within 14 hours when it could not be located within the pen. My inability to find the animal at that time was doubtless attributable to its concealment in vegetation that grew inside the enclosure.

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ZOOPLANKTON DYNAMICS IN A HIGH MOUNTAIN RESERVOIR OF SOUTHERN CALIFORNIA[1]

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The dynamics of the zooplankton community of eutrophic Big Bear Lake was studied from December 1976 through November 1978. The zooplankton community was dominated by the rotifer, *Keratella cochlearis,* in the spring; the copepod, *Diaptomus franciscanus,* in early summer; and by the cladocerans, *Daphnia pulicaria* and *Ceriodaphnia quadrangula,* for the remainder of the year. Annual abundance was bimodal with peaks in the spring and summer. The east end of Big Bear Lake had higher water temperatures, higher hypolimnetic dissolved oxygen concentrations, and greater phytoplankton standing crops than the west end of the lake. As a result, it supported significantly higher standing crops of zooplankton. Zooplankton abundance was significantly higher in 1978, a normal precipitation year, than in 1977, a drought year. Littoral rotifers, cladocerans, and copepods were commonly collected with the zooplankton, reflecting the shallow, weedy conditions of Big Bear Lake. Predator-prey and competitive interactions work to structure the zooplankton community composition while phytoplankton productivity and water quality conditions interact with these processes to determine population levels.

INTRODUCTION

Big Bear Lake, a high mountain reservoir in the San Bernardino mountains of southern California, was the subject of intensive limnological and fisheries investigations from November 1976 to November 1978. The reservoir was originally constructed to provide irrigation water for the Redlands-San Bernardino area but is now used chiefly for recreation. The importance of this reservoir to the recreational needs of Southern California and the economy of Big Bear Valley (resident population 7,000) is illustrated by weekend populations of more than 100,000 (Neste, Burdin, and Stone 1970). In mid-1976, anticipating acquisition of Big Bear Lake, the Big Bear Municipal Water District contracted with the California Department of Fish and Game and private consultants to undertake an ecological evaluation of Big Bear Lake aimed at developing a comprehensive lake restoration program.

Big Bear Lake is classified as a moderately eutrophic lake. High nutrient input from the surrounding areas and nutrient regeneration from the sediments has resulted in rapid cultural eutrophication (Siegfried, Herrgesell, and Kopache 1982; Siegfried 1982). Productivity, phytoplankton standing crop, and mean heat content increase west to east in Big Bear Lake (Siegfried *et al.* 1982).

Previous information about the Big Bear Lake zooplankton has been qualitative in nature (Goldman 1975). The present study, designed to determine the quantitative distribution and abundance of the zooplankton community, documents the dynamics of the zooplankton in Big Bear Lake from December 1976 to November 1978. The first year was a period of severe drought, resulting in the lowest water levels in 10 yrs, while the second year was a high water period in which lake volume reached capacity. The difference in water levels between

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years had important effects on the limnology of Big Bear Lake (Siegfried *et al.* 1982).

STUDY SITE

Big Bear Lake is located at an elevation of 2,055 m in a relatively small, east-west oriented basin in the San Bernardino Mountains of southern California (Figure 1). It was impounded in 1885 by construction of a dam across Bear Creek, a tributary of the Santa Ana River, and enlarged in 1911 by a new, higher dam. At maximum pool it has a surface area of 12.1 km^2, a mean depth of 7.38 m, and contains 89.3×10^6 m^3 of water. Differences in rainfall between 1977, a "drought" year, and 1978, a "normal" year, caused lake morphology to vary greatly (Table 1).

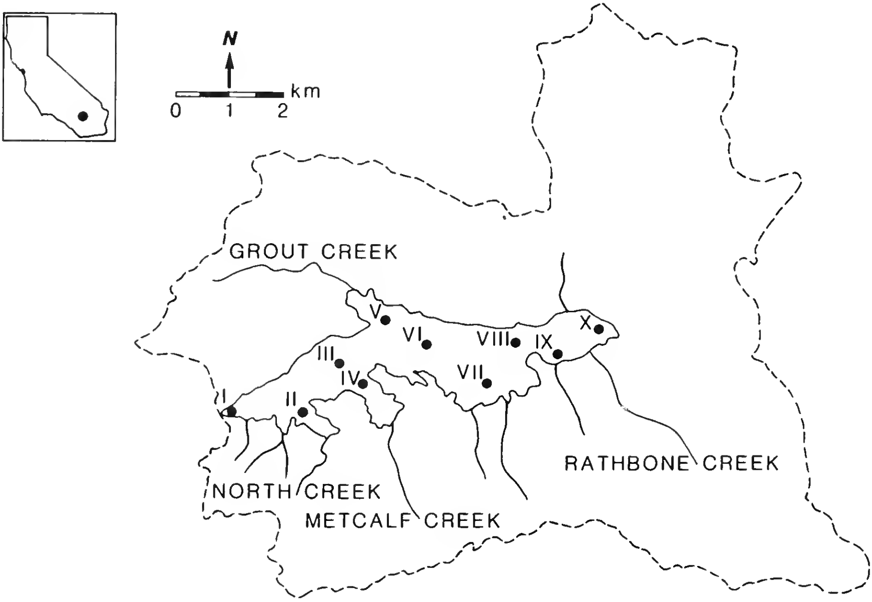

FIGURE 1. Map showing the location of Big Bear Lake, sampling sites, and major tributaries.

TABLE 1. Morphology of Big Bear Lake, 1977–1978.

		1977	*1978*
	Capacity	*Low (Dec)–High (May)*	*Low (Jan)–High (June)*
Area	12.1 km^2	8.00–8.88 km^2	8.34–11.58 km^2
Mean depth	7.38 m	4.78–5.13 m	4.95–7.10 m
Max depth	22.0 m	16.9–17.8 m	17.3–21.3 m
Length	9.05 km	9.05 km	9.05 km
Mean breadth	1.34 km	.88–.98 km	.92–1.28 km
Volume	89.3×10^6 m^3	$38.2–45.5 \times 10^6$ m^3	$41.5–82.2 \times 10^6$ m^3
Shoreline development	3.11	2.48–2.78	2.6–3.03
Mean annual precipitation	61 cm	33.4 cm	60.7 cm

Intermittent streams originating from snow melt and runoff constitute the main source of water for Big Bear Lake. Major filling occurs from January to May. Hypolimnetic water releases were made in the late summer and fall of most years but were discontinued in 1978. Average annual precipitation in the Big Bear drainage area is 61 cm. Air temperature varies from a summertime high of 30°C to a winter low of −15°C. The lake froze during the winters of 1977 and 1978, as it does during most winters. Spring and summer are characterized by afternoon west winds of 16–32 km hr^{-1}.

The lake basin is dominated by Jeffrey pine, *Pinus jeffreyi,* and white fir, *Abies concolor,* with pinion pine, *P. monophylla,* and western juniper, *Juniperus occidentalis,* on the higher slopes. Big Bear Valley contains the communities of Fawnskin (1,400 residents) on the north shore, Big Bear Lake (3,760 residents) on the south shore, and Big Bear City (1,610 residents) on the southeast end of Big Bear Lake. Each community is now sewered but numerous abandoned septic tanks and several nonsewered residences around the western end of the lake remain in the drainage basin.

Big Bear Lake typically stratifies in early spring, anoxia develops in the hypolimnion, and pH values in the epilimnion exceed 9.0 (Siegfried *et al.* 1982). Phytoplankton maxima occur in the spring and late summer. Diatoms dominate in early summer and blue-green algae dominate from mid-summer to fall. Dense macrophyte beds occur in the shallow areas of Big Bear Lake and frequent harvesting is necessary to maintain navigable channels in many nearshore areas. Hatchery reared rainbow trout, *Salmo gairdneri,* and naturally produced largemouth bass, *Micropterus salmoides,* bluegill, *Lepomis macrohirus,* and pumpkinseed, *L. gibbosus,* dominate the sport catch at Big Bear Lake (Siegfried, Pickard, and Herrgesell 1979).

METHODS

In 1976, 10 stations were established in Big Bear Lake to monitor the zooplankton community (Figure 1). In 1978, sampling was focused on Stations I, III, and VIII. The stations were sampled monthly during fall and winter of 1977 and 1978, biweekly in spring and summer of 1977, and triweekly in spring and summer of 1978. Water quality and phytoplankton samples were collected on the same dates and are reported in Siegfried *et al.* (1982).

Zooplankton were sampled with a diaphragm pump equipped with a hose and intake diffuser designed to regulate the incurrent velocity of water above the swimming velocities of zooplankton (Herrgesell 1975). The excurrent water from the pump was filtered through a No. 20 plankton net (mesh = 73μ). Plankton retained by the net were washed into plastic vials and preserved with 5% neutral formalin. On each sample date, triplicate, vertically integrated samples were collected from each site. From May to November 1978 additional samples were collected at each 2-m depth interval to characterize zooplankton vertical distribution patterns. Diel patterns of vertical distribution were determined from samples taken at 2-m depth intervals at Stations III and VIII every 4 h from 1200 h on 16 May to 0800 h on 17 May 1978.

The entire sample, or a subsample representing at least 28% of the entire sample, was placed in a Sedgewick-Rafter cell for taxonomic analysis and counting at 45×. Zooplankton were initially identified at the order or family level, but by 1978 they were identified at least to the generic level. Taxonomic identification followed Edmondson (1959). Cladoceran size distributions were determined by measurement of total body length exclusive of tail spine. Cladocerans were grouped by length intervals of 0.125-mm for _Daphnia_ spp. and 0.075-mm for _Ceriodaphnia_. Size-class specific weights were determined by oven drying 10 individuals of each size class at 60°C for 24 h, cooling over desiccant, and then collectively weighing them. Cladoceran egg ratios were determined by counting the number of eggs per species in the sample and dividing by the number of reproductive females.

RESULTS AND DISCUSSION

Zooplankton Community Composition and Abundance

Twenty-two species of crustacea and 19 species of rotifera were identified in zooplankton samples collected from Big Bear Lake during this study (Table 2). Limnetic forms, littoral forms, and forms adapted to both habitats were identified (Table 2). The large number of littoral forms collected in our plankton samples reflects the shallow, weedy conditions that characterize much of Big Bear Lake.

TABLE 2. Zooplankton Collected in Big Bear Lake, 1977–1978.

Cladocera

Alona spp. (2) *
Bosmina longirostris +
Camptocercus rectirostris *
Ceriodaphnia quadrangula +
Chydorus sphaericus * +
Daphnia parvula +
Daphnia pulicaria +
Daphnia laevis +
Diaphanosoma leuchtenbergianum +
Eurycercus lamellatus *
Graptoleberis testudinaris *
Leydigia sp.*
Macrothrix laticornis *
Pleuroxus sp.*
Simocephalus vetulus *

Copepoda

Diaptomus franciscanus +
Cyclops vernalis +
Eucyclops agilis *
Macrocyclops albidus *
Orthocyclops modestus * +
Harpacticoid *

Rotifera

Asplanchna sp. +
Brachionus calyciflous * +
Colurella sp. *
Conochilus unicornis +
Euchlanis sp. * +
Filina longiseta +
Hexarthra sp. +
Keratella cochlearis +
Keratella quadrata +
Lecane sp.*
Monostyla sp.*
Mytilina sp.*
Platyias patulus * +
Platyias quadricornis * +
Polyarthra sp. +
Rotaria neptunia *
Synchaeta sp.+
Trichocera sp.* +
Trichotria sp.*

\+ = pelagic
* = littoral

The zooplankton community of Big Bear Lake was dominated numerically by rotifers in the spring, by the copepod, _Diaptomus franciscanus,_ in early summer, and by cladocerans in late summer, fall, and winter (Figure 2). The annual abundance curve was typically bimodal, with peaks in the spring and late summer. The spring peak coincided with the spring diatom increase and was attributable to the response of rotifer populations to increased food availability and increasing temperatures. The late summer peak was attributable to cladoceran population increases. The dominance by cladocerans through much of the year is typical of more eutrophic systems (McNaught 1975).

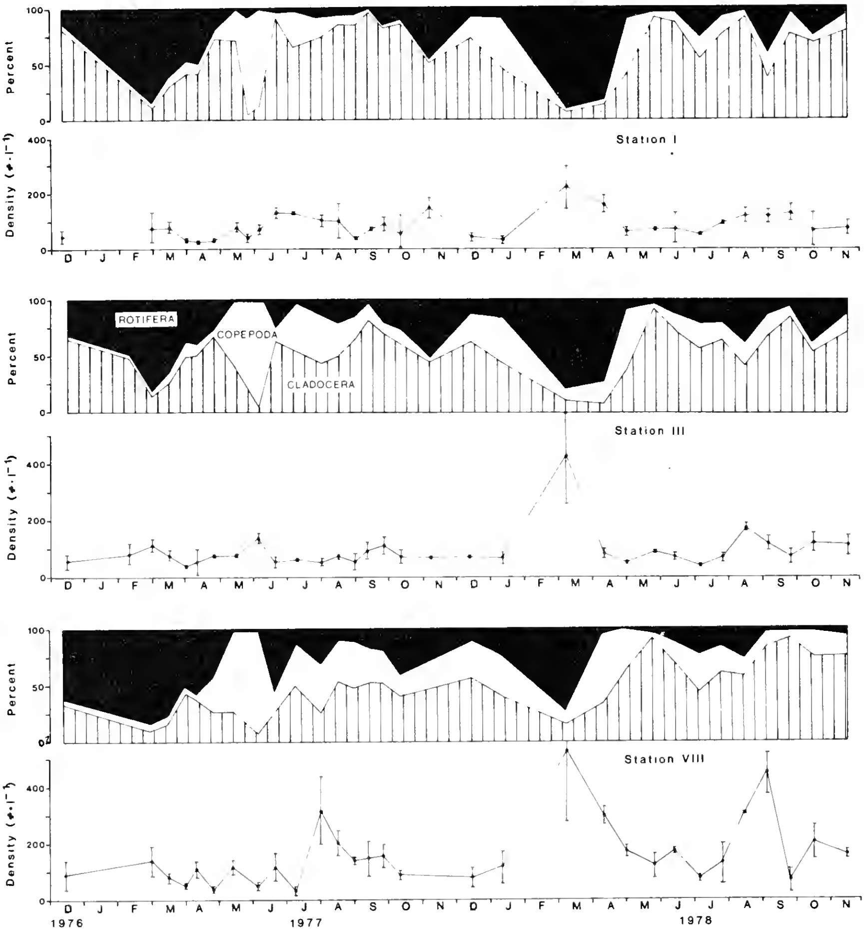

FIGURE 2. Percent composition and total zooplankton density with 95% confidence intervals at Stations I, III, and VIII, Big Bear Lake, California, December 1976–November 1978.

Seasonal patterns were consistent between stations and years except that in summer 1977 cladocerans represented less than 50% of the zooplankton present at Station VIII. Cladocera accounted for more than 50% of the zooplankton present at all stations in the summer and fall of 1978 and at Stations I and III in 1977. The difference between years at Station VIII was correlated to the reduced availability of pelagic habitats. In 1977 the water column at Station VIII was less than 5 m deep and macrophytes were abundant. Stations I and III were located in deeper portions of the lake and retained pelagic characteristics throughout the study period. In 1978 all stations were at depths greater than 8 m and were dominated by limnetic cladocerans in the summer and fall.

A two-way ANOVA (Sokal and Rohlf 1969) indicated that in 1977 and 1978 total zooplankton concentrations were significantly higher ($\alpha = 0.001$) at Station VIII than at Stations I or III. Several factors contribute to this situation. Water temperature, hypolimnetic oxygen concentration, and phytoplankton standing crop and productivity were generally higher at the east end (Siegfried *et al.* 1982). Given the more favorable physical environment at Station VIII, the greater phytoplankton productivity can support a greater zooplankton standing crop (McCauley and Kalff 1981). The prevailing west winds tend to transport zooplankton eastward contributing to higher population densities at the east end of the lake.

Zooplankton concentrations were generally higher in 1978 than in 1977. A one-way ANOVA (Sokal and Rohlf 1969) was used to assess the significance of these differences. Sample dates from February to November were paired and only those sample dates that were within 1 wk in corresponding years (e.g. Station I, 8 July 1977 and 5 July 1978) were included in the analysis. Mean surface temperatures at these stations on corresponding dates were always within 2°C. Zooplankton standing crop at all three stations was significantly ($\alpha = 0.05$) higher in 1978 than in 1977. A number of factors may have contributed to these differences, including improved water quality in 1978 (Siegfried *et al.* 1982), increased food availability, or changes in predation pressure.

Rotifera

The Big Bear Lake rotifer community exhibited a trimodal pattern of abundance, with peaks in the spring, late summer, and fall. Population lows occurred in winter and early summer (Figure 3). The spring (March) maximum was dominated by *Keratella cochlearis* ($\simeq$80% of rotifers collected). *K. cochlearis* is possibly the most common planktonic rotifer in temperate waters (Hutchinson 1967) typically having a large maximum in late spring or early summer, a minimum in June, and a secondary peak in mid-summer (Carlin 1943, Beach 1960). The spring maximum in Big Bear Lake reached a mean density of $\simeq$300 rotifers $\cdot l^{-1}$, with maximum density $\simeq 410 \cdot l^{-1}$, at Station VIII. *Keratella* was the dominant rotifer on all sampling dates from January to June in 1978, except at Station VIII in April when *Asplanchna*, a major predator of *Keratella* (Elliott 1977), dominated the rotifer community and reached maximum recorded densities of $11 \cdot l^{-1}$. The spring *Keratella* maximum occurred later and persisted longer at Station I than at Stations III and VIII. Cooler water temperatures at Station I may be an important factor in delaying the spring increase. A *Keratella* population minimum occurred at all stations in early summer, with a secondary peak developing in August.

Rotifer abundance declined sharply by April 1978 and reached a minimum in early May. Abundance then increased through the summer and peaked at Stations III and VIII in August and at Station I in early September. A later summer peak was also evident in 1977. The 1977 late summer maximum was dominated by *Polyarthra, Euchlanis,* and *Conochilus* at Stations III and VIII, but by *Hexarthra* at Station I. *Hexarthra* represented more than 60% of the total rotifers collected at Station I but only 5% and 0.1% at Stations III and VIII, respectively. *Hexarthra* is a warm water species which typically has a summer population maximum. Its dominance at Station I coincident with low disolved oxygen concentrations suggests a tolerance to low disolved oxygen tensions.

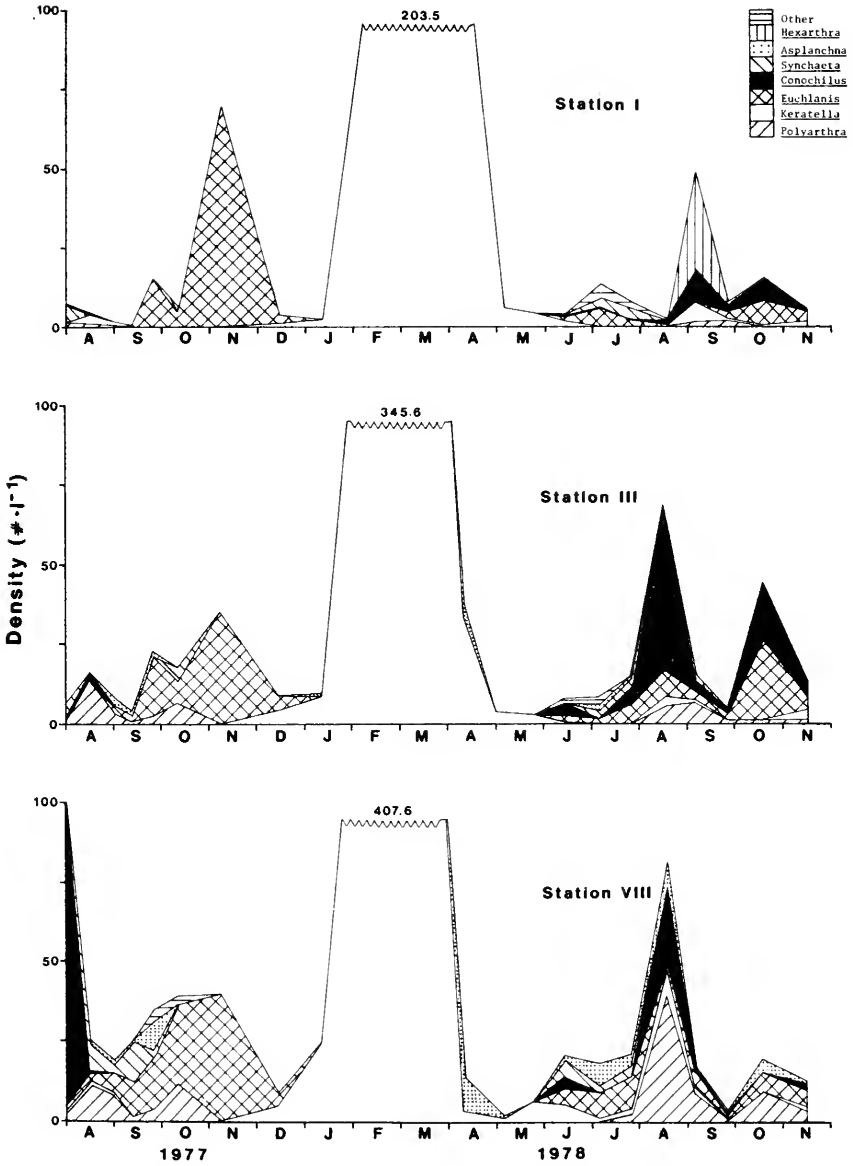

FIGURE 3. Rotifer community composition and density at Stations I, III, and VIII, Big Bear Lake, California, August 1977–November 1978.

Euchlanis dominated the late summer-fall rotifer community of Big Bear Lake in 1977 and 1978. *Euchlanis* generally appears in the plankton of temperate lakes only in late summer, usually associated with blue-green algal blooms (Hutchinson 1967). This was true of *Euchlanis* in Big Bear Lake, the fall maxima being associated with blooms of *Aphanizomenon flos-aquae.*

Rotifer abundance as well as species richness was generally greatest at Station VIII. Greater food avilability coupled with higher water temperatures and dissolved oxygen concentrations at Station VIII provided more favorable conditions for rotifer production. Low dissolved oxygen concentrations such as those at Station I restrict habitat available to sensitive species such as *Synchaeta, Conochilus,* and *Asplanchna* (Elliott 1977).

Crustacea

Cladocera

The limnetic cladoceran community of Big Bear Lake was dominated by *Daphnia pulicaria, Ceriodaphnia quadrangula,* and *Chydorus sphaericus* (Figure 4). These three species comprised greater than 90% of the cladocerans collected during this study. *D. pulicaria* and *Ceriodaphnia quadrangula* are common limnetic cladocerans through North America. *Chydorus sphaericus* is found in the littoral region of lakes and ponds throughout the world. Its occurrence in the plankton has been linked to the presence of blue-green algal blooms (Apstein 1896, Birge 1898, Wesenberg-Lund 1904, Berg and Nygaard 1929, and Patalas 1954). Although *C. sphaericus* was found in the plankton of Big Bear Lake throughout the year (Figure 4), it was abundant only during blooms of *Aphanizomenon flos-aquae* (Siegfried *et al.* 1982).

No significant between station differences in cladoceran composition could be detected (sign-test, $\alpha = 0.05$). *Daphnia pulicaria* and *Ceriodaphnia quadrangula* were dominant in the summer and fall of both 1977 and 1978. *Chydorus sphaericus* was a dominant member of the limnetic cladoceran community in the winter of 1977 and late-summer-fall 1978. The appearance of large numbers of *C. sphaericus* in the plankton is one of the more characteristic changes in plankton communities of strongly enriched waters (Brooks 1969).

Three population maxima occurred in the Big Bear Lake population of *D. pulicaria* in 1978; a small early spring peak, a larger peak in early summer, and the annual maximum in late summer (Figure 4). A late summer peak was also evident in 1977. This pattern was consistent at all stations although population density at Station VIII was significantly greater than that at Stations I and III ($\alpha = 0.001$). The annual pattern of *D. pulicaria* standing crop closely followed that of density (Figure 4).

Although male *D. pulicaria* and a few ephippia were produced from September to November, *D. pulicaria* overwintered in the free swimming stage primarily as large females (Figure 5). Mean *D. pulicaria* length in January was 1.78 mm, with individuals as long as 2.75 mm encountered. Asexual reproduction continued through the winter. As water temperature increased in the spring and summer, mean *D. pulicaria* length decreased as young were recruited and size at maturity decreased. Brood size generally declined through the spring. We attributed this decline to the reduction in size at maturity and poor food availability. Increases in mean brood size preceded population increases in spring and summer, and coincided with increased phytoplankton densities (Siegfried *et al.* 1982). No significant between station differences were detected.

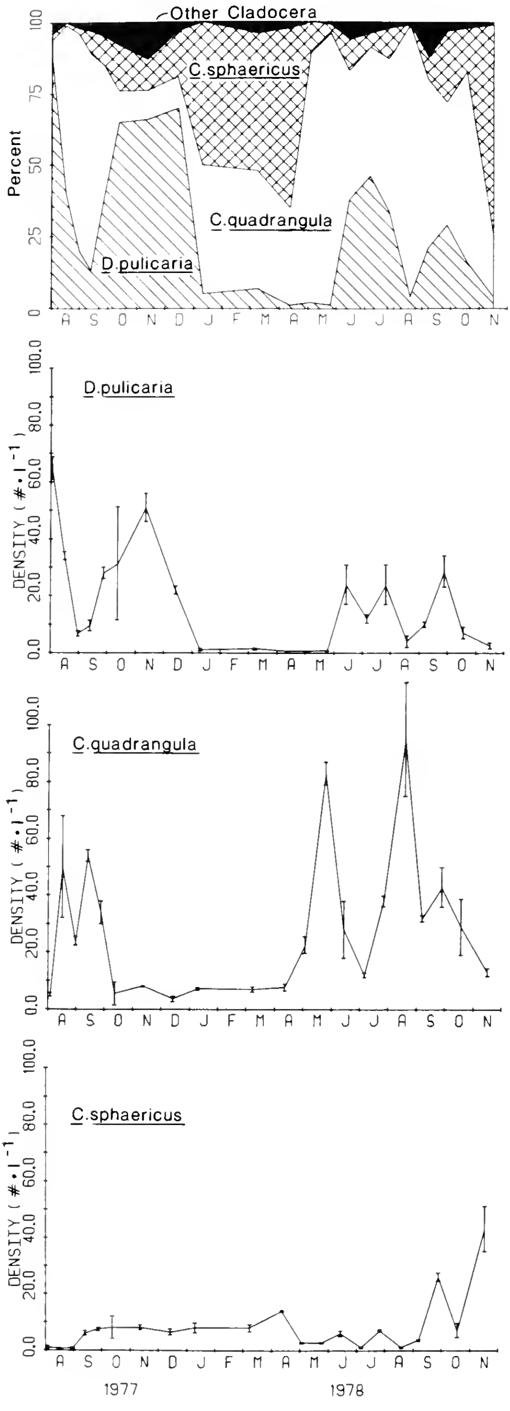

FIGURE 4a. Cladocera community composition and abundance at Station I, August 1977–November 1978. Vertical lines represent ± one standard deviation about the mean for each date.

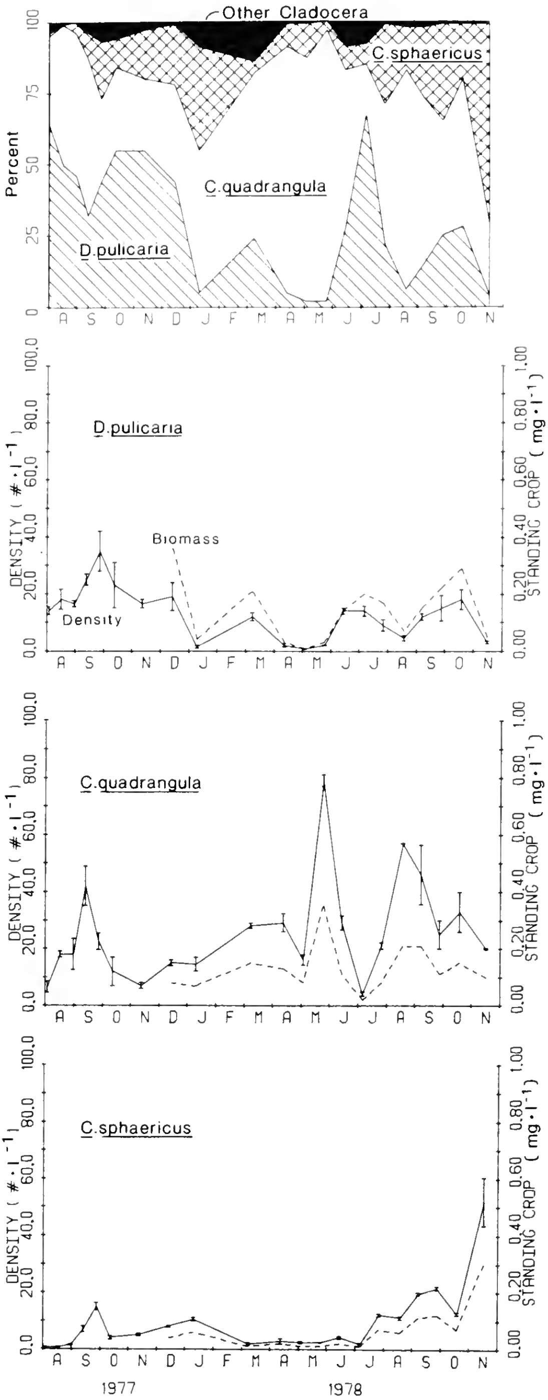

FIGURE 4b. Cladocera community composition and abundance at Station III, August 1977–November 1978. Vertical lines represent ± one standard deviation about the mean for each date.

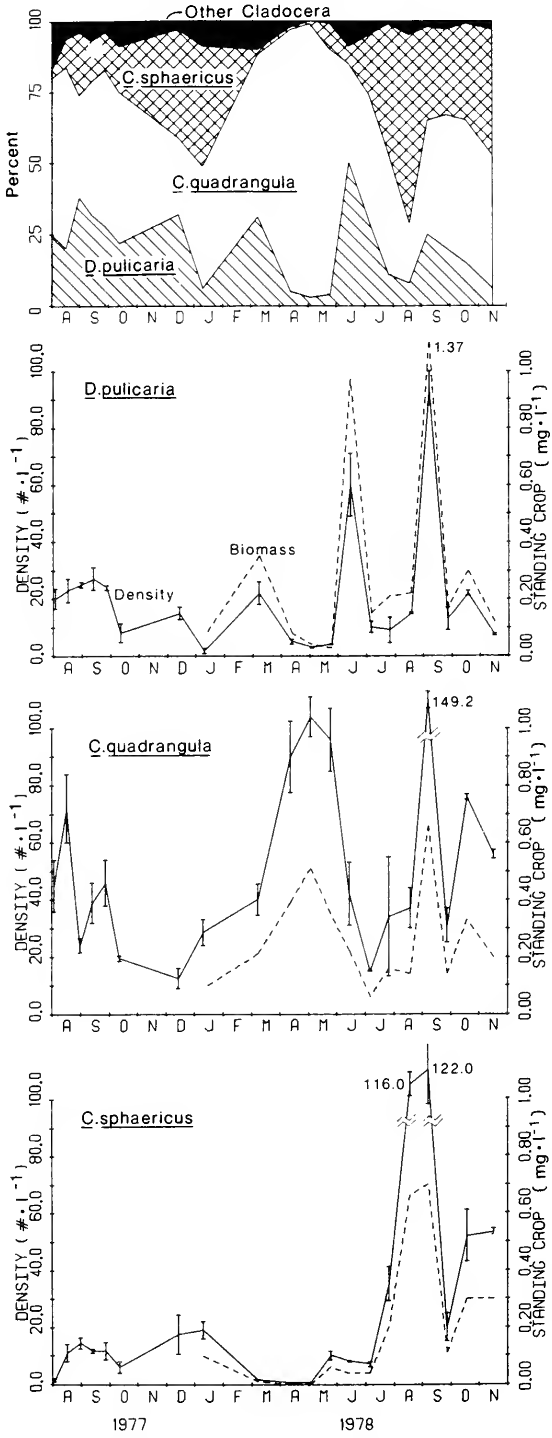

FIGURE 4c. Cladocera community composition and abundance at Station VIII, August 1977–November 1978. Vertical lines represent ± one standard deviation about the mean for each date.

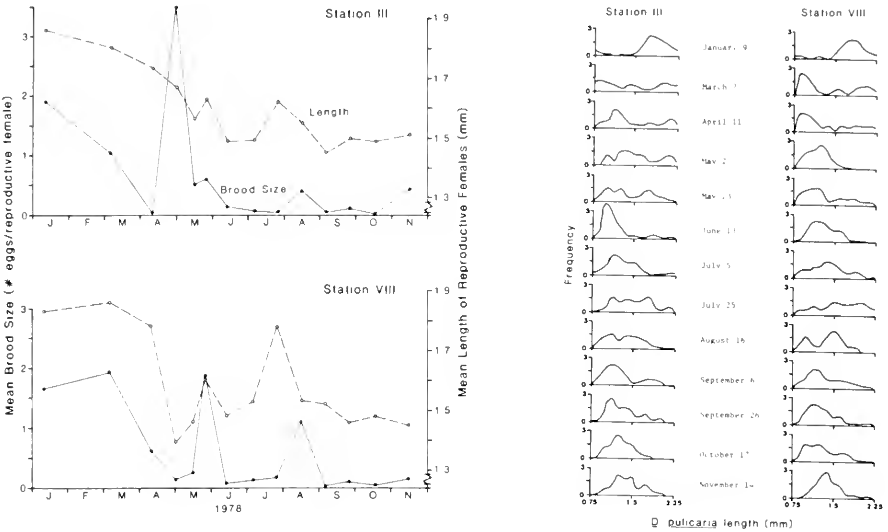

FIGURE 5. *Daphnia pulicaria* egg density, mean size of reproductive females, and size frequency distribution at Stations III and VIII, Big Bear Lake, California, January–November 1978.

During stratification the *D. pulicaria* population was concentrated just above the thermocline (Figure 6). Dissolved oxygen depletion in the hypolimnion apparently restricted the *D. pulicaria* population to the upper strata. In the spring, prior to stratification, *D. pulicaria* was concentrated near middepth during the day and exhibited a distinct noctural ascent (Figure 6).

Ceriodaphnia, a potential competitor of *Daphnia* (Lynch 1978), exhibited a similar life history, but one slightly out of phase with *D. pulicaria* in Big Bear Lake (Figure 4). *Ceriodaphnia quadrangula* population maxima generally occurred earlier than *D. pulicaria* maxima. The nonsynchrony of population trends of these two cladocerans may be, in part, a reflection of competitive interactions. *Daphnia* and *Ceriodaphnia* share the same resource base and both can limit the abundance of their resources (phytoplankton and bacteria) (Lynch 1978). Competition between adult *Ceriodaphnia* and juvenile *Daphnia* may have limited the spring maximum of *D. pulicaria.* Although *D. pulicaria* brood size was highest in the spring, the annual population maximum did not occur until late in the year. Replacement of *D. pulex* by *Ceriodaphnia* as the dominant member of the zooplankton community has been related to competition between adult *Ceriodaphnia* and juvenile *D. pulex* (Lynch 1978). Competitive interactions of this type may be mediated by predation by planktivorous fish in Big Bear Lake.

Ceriodaphnia quandrangula life history in Big Bear Lake was similar to that of *D. pulicaria.* The winter was passed either as large free-swimming reproductive females or as juveniles which matured slowly through the winter (Figure 7). Males and ephippia were not produced by *Ceriodaphnia* in Big Bear Lake in 1978.

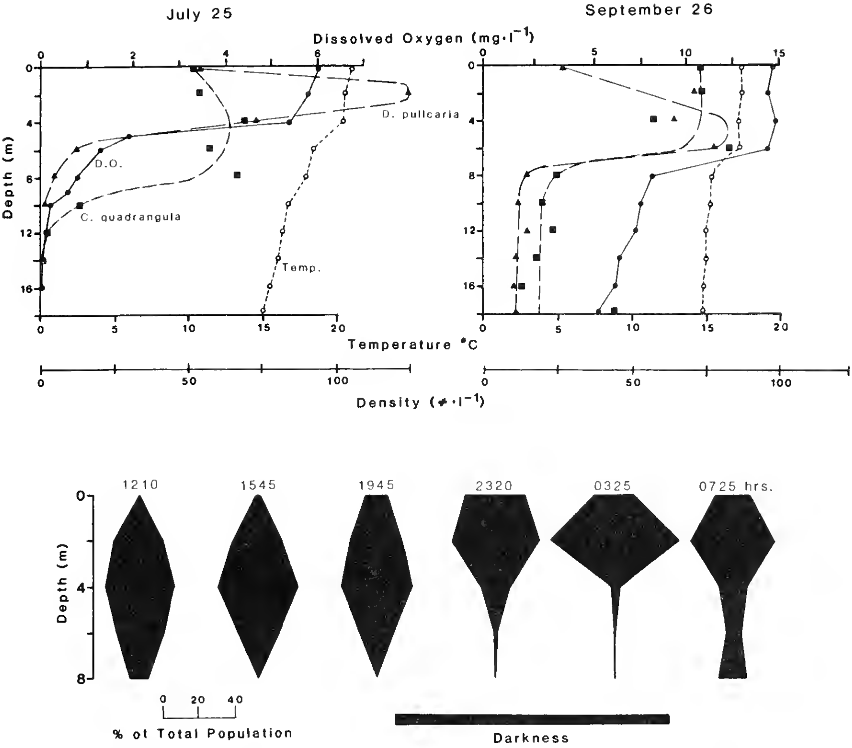

FIGURE 6. Vertical distribution of *Daphnia pulicaria* (▲) and *Ceriodaphnia quadrangula* (■) in relation to dissolved oxygen concentration (•) and temperature (o) at Station I, 25 July and 26 September 1978, and diel vertical distribution at Station VIII, 17 May 1978, Big Bear Lake, California (curves fitted by eye).

Reproduction and development of *C. quandrangula* occurred at temperatures as low as 3.7°C. This contrasts with results of studies in other lakes (Kwik and Carter 1975, Allan 1977) which showed biological zero, or the temperature at which the developmental rate is negligible for *Ceriodaphnia quadrangula*, was between 8.5°C and 12.4°C. Brood size was greatest during winter, declined to a low level in early spring, reached secondary peaks in May and August, and declined to an annual minimum in September. Brood size maxima coincided with phytoplankton standing crop maxima (Siegfried *et al.* 1982). Mean size of reproductive females peaked in March and generally declined through the summer. Although mean size of reproductive females was similar at each station, *C. quadrangula* mean brood size was significantly higher at Station VIII than at Station I. We attributed this to greater food availabilty at Station VIII.

Ceriodaphnia quadrangula occurred at lower dissolved oxygen concentrations than *D. pulicaria* (Figure 6). *C. quadrangula* populations were evenly distributed throughout the epilimnion and declined with depth and declining dissolved oxygen concentrations. *C. quadrangula* did not exhibit a pronounced noctural ascent during the nonstratified period as did *D. pulicaria.*

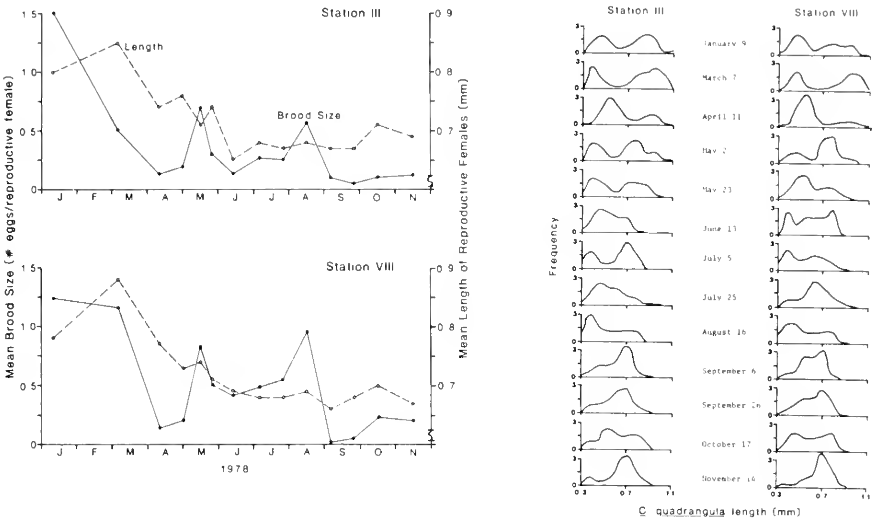

FIGURE 7. *Ceriodaphnia quadrangula* egg density, mean size of reproductive females, and size frequency distribution at Stations III and VIII, Big Bear Lake, California, January–November 1978.

Predation by planktivorous fish can be an important force structuring the zooplankton community of lakes (Brooks and Dodson 1965, Galbraith 1967, Brooks 1968). The planktivorous fish of Big Bear Lake, rainbow trout, bluegill, and pumpkinseed, preyed almost exclusively on *Daphnia pulicaria,* which accounted for more than 99% of the zooplankton in fish stomachs examined during this study (Figure 8). Predation pressure was greatest on the larger sizes of *D. pulicaria.* Centrarchids rarely captured *D. pulicaria* less than 1.25 mm long while rainbow trout fed primarily on *D. pulicaria* greater than 1.50 mm long. The median size of *D. pulicaria* found in fish stomachs was about 0.50 mm larger than the median size of *D. pulicaria* in the zooplankton.

This size and species specific selection may have mediated the competitve interaction between *D. pulicaria* and *C. quadrangula.* Large *Daphnia* have a competitive advantage over *Ceriodaphnia* but juvenile *Daphnia* are at a competitive disadvantage with *Ceriodaphnia* (Lynch 1978). Removal of large *D. pulicaria* by lake planktivores presumably maintains conditions under which *Ceriodaphnia* is competitively superior. This interaction may shift seasonally and result in shifts in cladoceran dominants. Centrarchid fry consume a more diverse zooplankton assemblage than do larger planktivores in Big Bear Lake. *C. quadrangula* comprised more than 50% of the zooplankton consumed by centrarchid fry examined in this study. The centrarchids of Big Bear Lake spawn from June (largemouth bass) to August (pumpkinseed) (Siegfried *et al.* 1979). Heavy predation by centrarchid fry on *C. quadrangula* may be responsible for the summertime maxima of the *D. pulicaria* population.

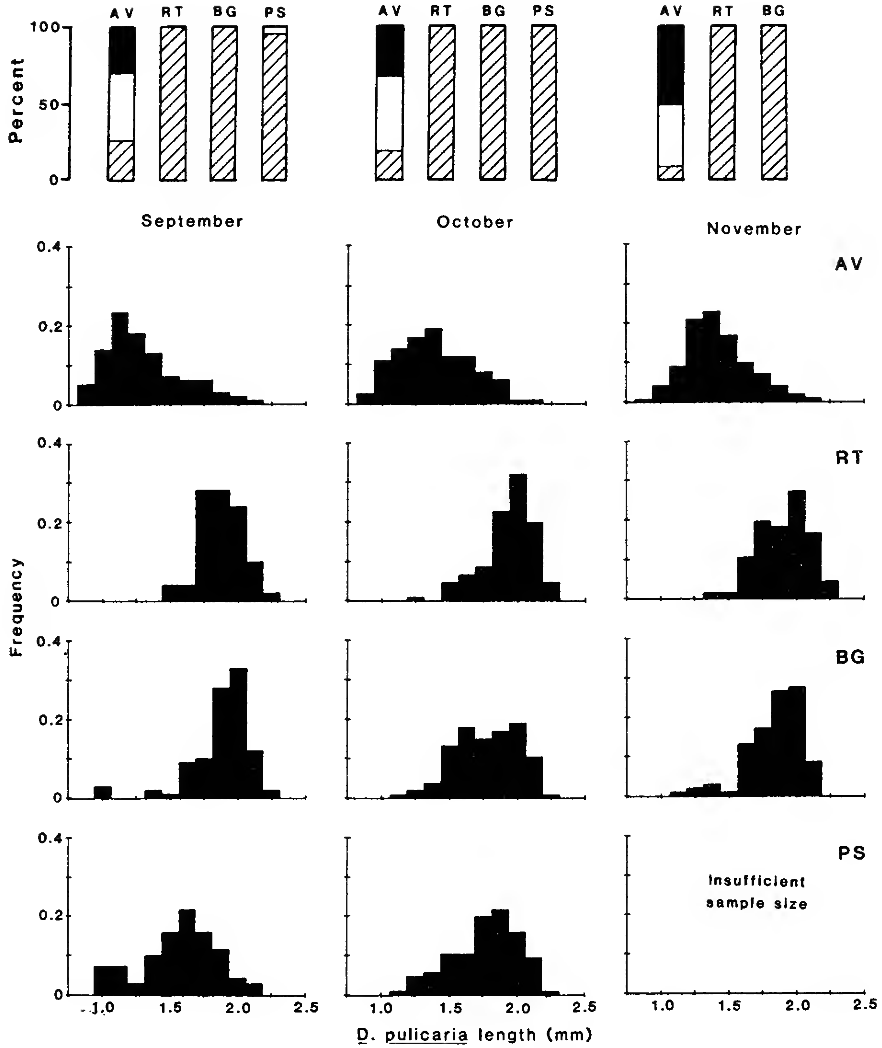

FIGURE 8. Species composition by numbers of Cladocera present in the Big Bear Lake plankton and in Big Bear Lake gamefish stomachs, and size-frequency distribution of *D. pulicaria* in the lake and in fish stomachs during September–November, 1978 (AV = available in environment, RT = rainbow trout, BG = bluegill, PSD = pumpkinseed; upper figure: Black = *Chydorus,* Cross hatched = *D. pulicaria,* White = *Ceriodaphnia*).

Copepoda

Diaptomus franciscanus was the dominant limnetic copepod in Big Bear Lake, particularly in spring at Stations III and VIII (Figure 9). *D. franciscanus* has a prolonged reproductive period in Big Bear Lake, producing several generations per year. Population peaks occurred in spring and late summer-early fall. *D. franciscanus* nauplii were present throughout the study (Figures 9 and 10). *D. franciscanus* overwinters primarily in late copepodid stages which mature and reproduce in early spring, producing the first generation (Figure 10). Hatching from resting eggs may also contribute to the spring nauplii peak. The spring generation develops to adults by May and gives rise to the first summer generation. Reproduction continues through the summer. The late summer-early fall generation appears to give rise to the overwintering population.

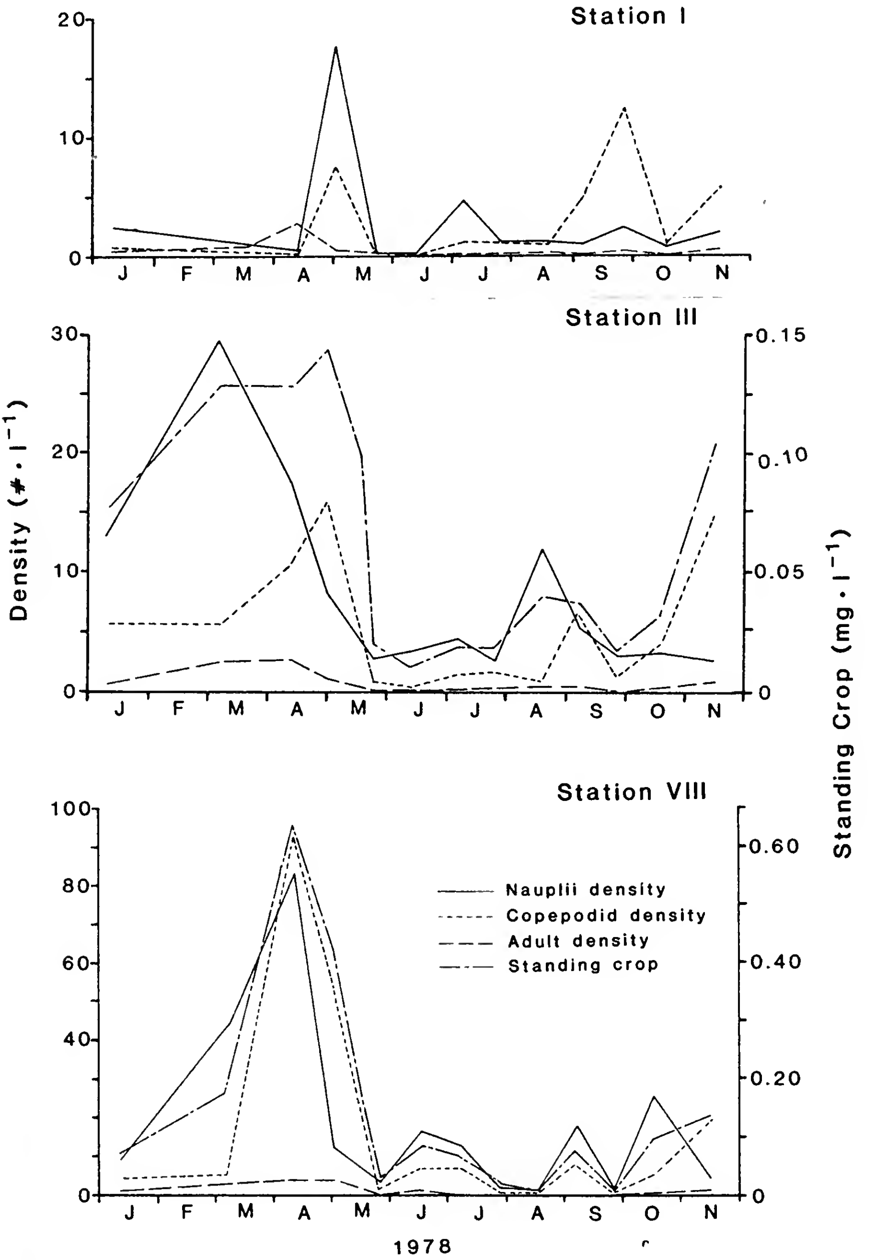

FIGURE 9. *Diaptomus franciscanus* and cyclopoid nauplii, copepodid, and adult abundance at Station I, III, and VIII, Big Bear Lake, California, January–November 1978.

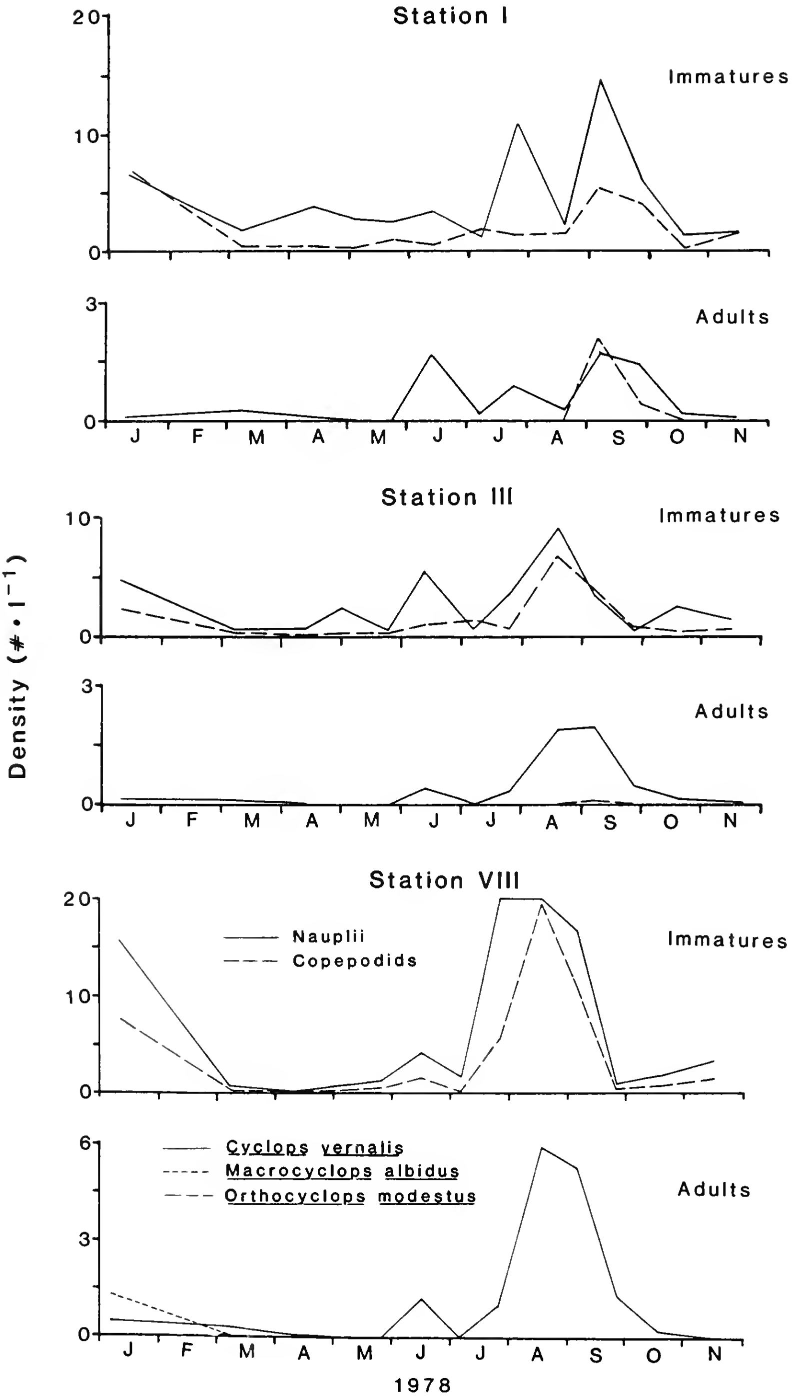

FIGURE 9. (Continued)

D. franciscanus standing crop peaked in the spring, exceeding 0.60 mg · l^{-1} at Station VIII. Both density and standing crop of *D. franciscanus* decrease east to west in Big Bear Lake (Figure 9). Station VIII had significantly greater ($\alpha = 0.01$) *D. franciscanus* standing crop than did Station III which had greater standing crop than did Station I. The gradient in standing crop is attributable to east-west temperature and phytoplankton standing crop differences. Increased mean temperature accelerates development times of *Diaptomus* generations and significantly increases *Diaptomus* population production (Carter 1974). Diaptomid clutch size varies with food supply, being higher under conditions of high food availability and decreasing with decreasing food availability (Comita and Anderson 1959, Czecznga 1960). The greater heat content at Station VIII, coupled with higher phytoplankton standing crops (Siegfried *et al.* 1982) may contribute to significantly greater diaptomid production at this station.

D. franciscanus was present throughout the water column during the spring and fall overturns but was restricted to the epilimnion during stratification (Figure 11). Maximum density occurred beweer 2–6 m in the spring and at the surface during stratification. Diel sampling in May, when *D. franciscanus* was particularly abundant, indicated no prominent vertical migration of any life stage of *D. franciscanus* in Big Bear Lake.

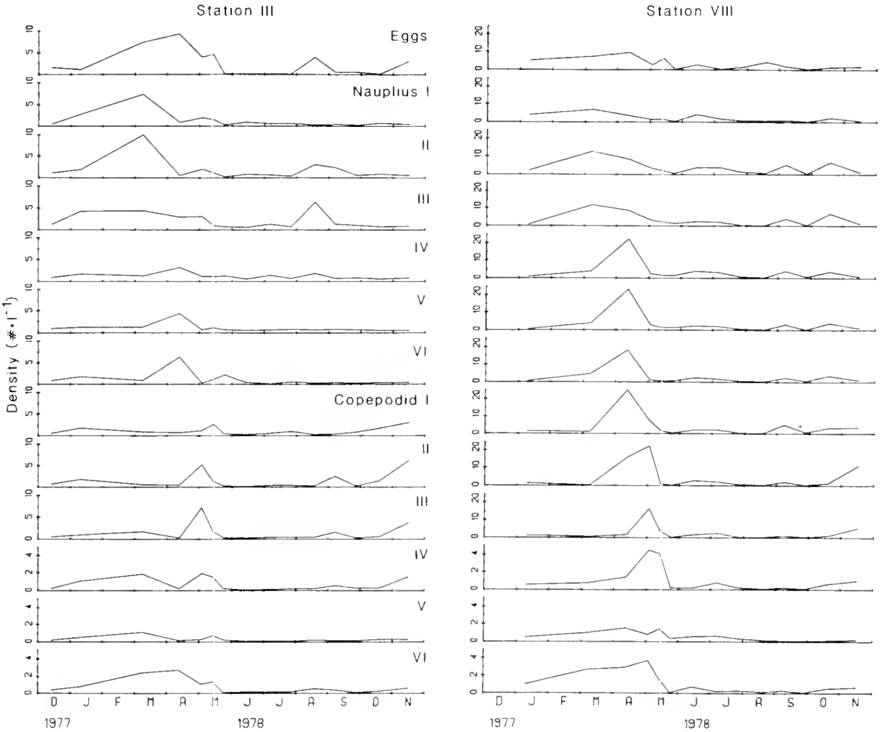

FIGURE 10. Mean density of *Diaptomus franciscanus* eggs, nauplii, and copepodid stages at Stations III and VIII, Big Bear Lake, California, January–November 1978.

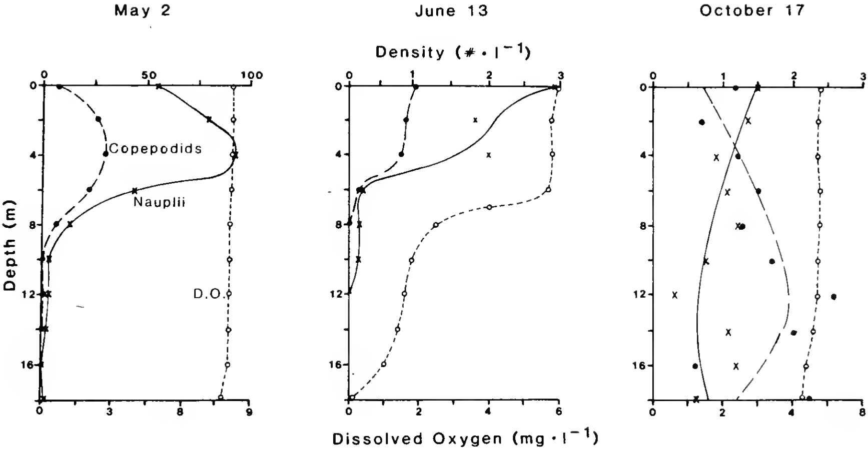

FIGURE 11. Vertical distribution of *Diaptomus franciscanus* nauplii and copepodids, in relation to dissolved oxygen concentration at Station I, 2 May, 13 June, and 17 October 1978 (curves fitted by eye).

Cyclopoid copepod population peaks occurred in August and September in Big Bear Lake. *Cyclops vernalis* was the dominant cyclopoid copepod at all stations. *Macrocyclops albidus* and *Eucyclops agilis,* two primarily littoral copepods, were present at Station VIII in late winter and early spring, but were not taken at Stations I and III. *Orthocyclops modestus* was present in the hypolimnion at Stations I and III in late summer, but absent at Station VIII which was mixed to the bottom. We were unable to separate the early life history stages of cyclopoid copepods so no detailed accounts of life histories will be presented. *Cyclops vernalis* appears to have at least two generations per year in Big Bear Lake, a minor one in early summer and a major one in late summer.

Annual differences in copepod dynamics could not be examined because of incomplete taxonomic determinations in 1977. Maximum cyclopoid copepod densities were about twice as high in 1978 as in 1977, but calanoid maxima were similar between years. Cyclopoid predation on calanoid nauplii and copepodids has been shown to be an important factor limiting *Diaptomus* populations (McQueen 1969, Confer 1971) and may have been significant in Big Bear Lake in 1978.

CONCLUSIONS

The zooplankton community of Big Bear Lake was typical of eutrophic systems. The community was dominated for much of the year by the cladocerans, *Ceriodaphnia quadrangula* and *Daphnia pulicaria.* Littoral rotifers, cladocerans, and copepods were commonly collected in our zooplankton samples, reflecting the shallow, weedy conditions that characterize much of Big Bear Lake. East-west phytoplankton productivity and water quality gradients have important effects on the productivity of all major groups of zooplankton in Big Bear Lake. Mean heat content, phytoplankton standing crop and phytoplankton productivity were greatest at the east end of Big Bear Lake. Higher mean water temperatures accelerated generation times and higher phytoplankton standing crop and productivity supported larger clutch sizes, thus significantly increasing zooplankton production at the eastern end of Big Bear Lake. Higher dissolved oxygen concentrations at the east end of the lake were also more favorable for zooplankton growth and survival. Predator-prey and competitive interactions work to stucture the zooplankton community composition while phytoplankton productivity and water quality conditions interact with these processes to determine population levels. Zooplankton populations were generally higher in 1978, when water levels were near normal for Big Bear Lake, than in 1977, a drought year. The major water quality differences between years was the greater heat content of Big Bear Lake in 1978 than in 1977.

ACKNOWLEDGMENTS

This study was funded through a contractual agreement between the Big Bear Municipal Water District and the California Department of Fish and Game (Agreement 55-867). We wish to thank the board of BBMWD and the manager, S. Foulkes, for their support, cooperation and patience throughout this study. We also extend our thanks to P. Herrgesell for his input during all phases of this study and to A. Pickard, W. Loudermilk, J. Gustafson and B. Louks for assistance in the field and laboratory.

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Calif. Fish and Game 70(1): 39–52 1984

THE BENTHOS OF A EUTROPHIC MOUNTAIN RESERVOIR: INFLUENCE OF RESERVOIR LEVEL ON COMMUNITY COMPOSITION, ABUNDANCE, AND PRODUCTION [1]

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The benthos of Big Bear Lake, California was studied from December 1976 to November 1978. Oligochaetes and chironomid larvae dominated the benthic community, accounting for $>95\%$ of the macrobenthic invertebrates collected at each study site. *Procladius bellus* and *Chironomus plumosus* were the dominant chironomid larvae of the lake. The general pattern of abundance was a spring population maximum followed by a decline to a late summer minimum and a recovery to a secondary peak in fall-early winter. Benthos abundance was significantly greater in 1977, a drought year, than in 1978, a high water year, at all sites except the deepest site, Station 1. The difference was related to oxygen depletion at each site in 1978 but only at Station 1 in 1977.

***C. plumosus* and *P. bellus* larvae occurred at nearly all of the 95 sites sampled in the study. *P. bellus* was generally more abundant but *C. plumosus,* being larger, dominated the standing crop. *P. bellus* had a bivoltine life cycle in Big Bear Lake, emerging in the spring and fall, while *C. plumosus* had a univoltine life cycle with emergence in spring. Oxygen depletion differences had a significant effect on chironomid larvae abundance at each study site. Annual production of *P. bellus* was reduced from 2.94 g AFDW $\bullet$ $m^{-2}\bullet yr^{-1}$ in 1977 to 0.83 g AFDW $\bullet$ $m^{-2}\bullet yr^{-1}$ in 1978. *C. plumosus* production declined from 3.85 g AFDW $\bullet^{-2}m\bullet yr^{-1}$to 1.38 g AFDW $\bullet$ $m^{-2}\bullet yr^{-1}$.**

The disappearance of chironomid larvae from the benthos during anoxic conditions appears to involve toxic effects as well as oxygen depletion. Un-ionized ammonia concentrations exceed critical levels for fish and may be harmful to invertebrates. Hypolimnetic aeration appears to be beneficial to the benthos of Big Bear Lake. Treatment of a test plot with the herbicide dichlobenil to control macrophytes significantly reduced the normally diverse littoral fauna to one composed exclusively of oligochaetes.

INTRODUCTION

Big Bear Lake was the subject of intensive limnological and fisheries investigations from November 1976 to November 1978. The reservoir was originally constructed to provide irrigation water for the Redlands-San Bernardino area but is now used chiefly for recreation, i.e., fishing and boating. The importance of this reservoir to the recreational needs of southern California and the economy of Big Bear Valley (resident population 7,000) is illustrated by weekend populations of more than 100,000 (Neste, Brudin, and Stone 1970). In mid-1976, in anticipation of acquiring ownership of Big Bear Lake, the Big Bear Municipal Water District contracted with the California Department of Fish and Game and private consultants to develop and implement an ecological evaluation of Big Bear Lake aimed at producing a comprehensive lake restoration program.

Big Bear Lake is classified as a moderately eutrophic lake. High nutrient input

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[1] New York State Museum, Science Service, Journal Series No. 359. Accepted for publication March 1983.

from the surrounding areas and nutrient regeneration from the sediments has resulted in rapid cultural eutrophication (Siegfried, Herrgesell, and Kopache 1982; Siegfried 1982). Productivity, phytoplankton standing crop, and mean heat content increase west to east in Big Bear Lake (Siegfried *et al.* 1982).

The benthos occupies an important position in the lake system, serving as a link between the primary producers and decomposers, and higher trophic levels. The benthos also plays an important role in the cycling of nutrients in lake systems (Gardner, *et al.* 1981). The benthic community can also serve as a useful indicator of environmental conditions. Lake management decisions may affect all levels of the Big Bear Lake ecosystem. It is therefore important to develop information on each major community of the lake in order to evaluate impacts of various management strategies. The present study documents the dynamics of the Big Bear benthos community from December 1976 to November 1978 and evaluates the response of the community to reservoir water level stabilization, hypolimnetic aeration, and dichlobenil treatment to control macrophytes.

STUDY SITE

Big Bear Lake is located in a relatively small, east-west oriented basin at an elevation of 2,055 m in the San Bernardino Mountains of southern California (Figure 1). The lake and its basin are described in Siegfried *et al.* (1982) and Siegfried (1982).

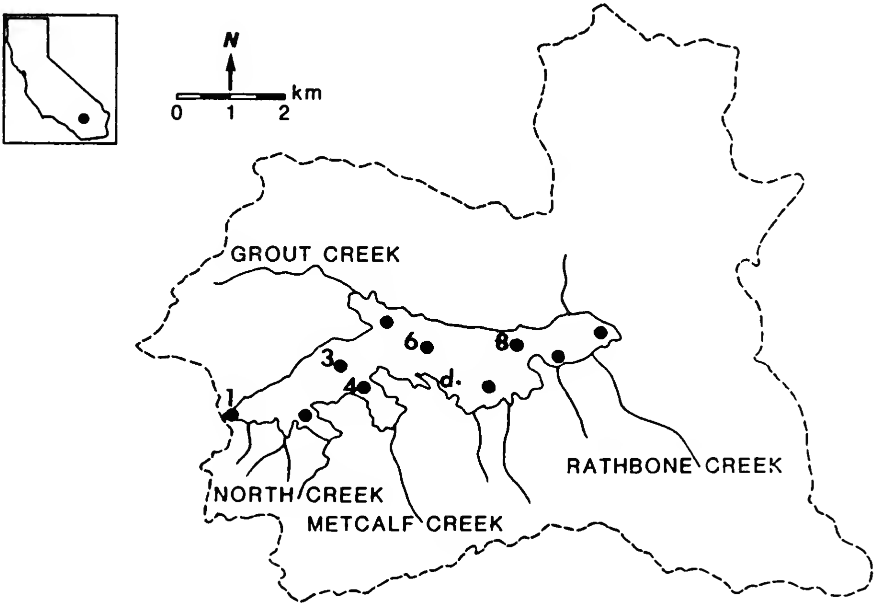

FIGURE 1. Map of Big Bear Lake showing sampling sites and major tributaries. Numbered sites were sampled through 1978, others were sampled only through 1977, d = dichlobenil test site.

The first year of study covered a period of severe drought resulting in the lowest water levels in 10 years, while the second year covered a wet period in which lake volume was at or near capacity. The difference in water levels between years had important effects on the limnology of Big Bear Lake (Siegfried *et al.* 1982). One of the most important effects was the change in hypolimnetic dissolved oxygen concentrations. During the drought year, stratification and hypolimnetic dissolved oxygen depletion occurred only at Station 1 at the west end of the lake. The lake water mixed and oxygen concentrations remained relatively high all year throughout the rest of the lake. In 1978, a high water year, stratification and severe oxygen depletion occurred at all midlake study sites. Because of lake level fluctuations, depth varied considerably between years at each site (Table 1). The substrate at all sites was primarily a fine organic-rich ooze.

TABLE 1. Mean Depth of Benthos Study Sites, Big Bear Lake, California, 1977 and 1978

Station	*Mean depth (m)*	
	1977	*1978*
1	18	20
3	9	11
6	8	10
8	8	10

MATERIAL AND METHODS

Ten sites, four located in the midlake region, and six in the major coves and inlets, were studied in 1976–1977 (Figure 1). The midlake stations and Station 4 were also studied in 1978. An additional site treated with dichlobenil to control macrophyte growth was studied in 1978 (Figure 1, d). Each site was sampled monthly except during the ice covered period; then samples were collected only when ice conditions permitted. Synoptic collections, consisting of a single benthos sample from 95 sites throughout Big Bear Lake, were made in March, June, September, and December 1977.

An Ekman grab was used monthly to obtain three replicate samples from each study site. These grabs were sieved in the field (mesh = 0.059 mm). The samples were preserved in buffered formalin and stained with Rose-Bengal tissue stain. Samples were sorted at the laboratory using a large magnifying lens and the benthic organisms identified and counted using a binocular dissecting and compound microscopes. Chironomid taxonomic determinations were based on Roback (1957) and Wirth and Stone (1963). The entire sample was counted except when oligochaetes were exceptionally abundant, necessitating subsampling.

The body length of each chironomid larva was determined to the nearest 1 mm in a grided petri dish. Production of the dominant chironomid larvae was determined by the length-frequency method (Hynes and Coleman 1968, Hamilton 1969). Size-specific ash free dry weights (AFDW) were calculated from regressions presented by Johnson and Brinkhurst (1971).

RESULTS AND DISCUSSION

Benthos Composition and Abundance

Oligochaetes and chironomid larvae dominated the benthic community of Big Bear Lake (Figure 2). Collectively, they accounted for more than 95% of all macrobenthic invertebrates collected at each study site. The oligochaetes belong to the families Naidae and Tubificidae. *Procladius bellus* and *Chironomus* *plumosus* larvae were the dominant chironomids of the lake. *Microcricotopus* sp. larvae were often dominant in benthic samples from macrophyte zones and *Glyptotendipes* sp. was occasionally abundant at some of the deeper sites.

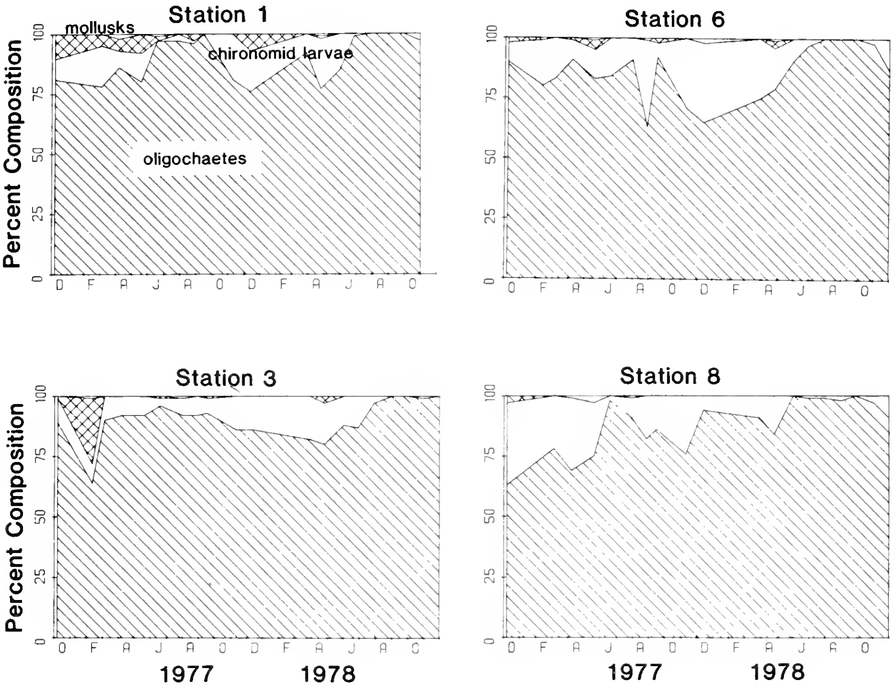

FIGURE 2. Composition of benthos at Big Bear Lake Study sites, December 1976–November 1978.

The dominance of oligochaetes in the macrobenthos is typical of eutrophic waters (Beeton 1961, Thut 1969). Oligochaetes generally increase in dominance in the benthos during the process of eutrophication (Wetzel 1975). Lake Erie provides an excellent example of the effects of eutrophication on benthos composition, particularly in relation to the increased dominance of oligochaetes. In 1930, Lake Erie was oligotrophic and the benthic community was dominated by the mayfly, *Hexagenia*, and oligochaetes comprised only about 1% of the benthos (Wright 1955); but by 1958 Lake Erie had become eutrophic and oligochaetes comprised more than 60% of the benthic fauna (Beeton 1961).

Extreme oxygen depletion, characteristic of eutrophic lakes, eliminates most benthic organisms other than oligochaetes. This is illustrated in a comparison of benthos composition in Big Bear Lake in 1977 and 1978. In 1977, the drought year, the lake mixed to the bottom through the summer, aerating the entire water column at all study sites except Station 1. Station 1, located in the deepest portion of Big Bear Lake, stratified and anoxia developed in the hypolimnion. During the period of stratification (June–September), oligochaetes represented 97–100% of benthic macroinvertebrates collected at Station 1, but chironomid larvae remained an important component of the benthos at the other sites. In

1978 water levels were high and stratification extended to all the study sites from June through September. Oligochaetes were about the only forms collected from the lake bottom during the 1978 stratified period (Figure 2).

The littoral zone of Big Bear Lake supported a much more diverse fauna. The amphipod, *Hyalella azteca,* damsefly and dragonfly naiads, and gastropods as well as chironomid larvae and oligochaetes were important components of the littoral macrobenthos. The presence of macrophyte beds and high dissolved oxygen concentrations provided more favorable and diverse habitat for macroinvertebrates.

Benthos densities ranged from 510 individuals • m^{-2} at Station 1 in September 1978 to 88,670 individuals • m^{-2} at Station 6 in April 1977 (Figure 3). The general pattern of abundance was a spring population maximum followed by a general decline in abundance to a late summer minimum followed by a recovery and a secondary peak in fall-early winter. Except for Station 1 in 1977 this general pattern was evident at each station during both years of study (Figure 3). The spring peaks coincided with increasing water temperatures and high dissolved oxygen concentrations throughout the water column (Siegfried *et al.* 1982) and also with the spring diatom and rotifer abundance maxima. This provided an abundant source of sedimenting organic matter for the deposit feeding benthos. The decline in abundance through the summer can be attributed, at least in part, to the depletion of dissolved oxygen in the hypolimnion, particularly in 1978. After fall overturn there was an increase in benthos density at all sites.

Application of the sign test to density differences at each station, paired by months of each year (Siegel 1956), indicate a significant difference ($\alpha = .002$) in density at Stations 3, 6, and 8 between 1977 and 1978. Benthic abundance was significantly greater at each of these sites in 1977. No significant difference between 1977 and 1978 densities was evident at Station 1. Station 1 experienced anoxia in both 1977 and 1978 (Siegfried *et al.* 1982) and benthos abundance was uniformly low both years of study. The remaining sites experienced anoxia only in 1978 (Siegfried *et al.* 1982).

Friedman's Randomized Block Test (Sokal and Rohlf 1969) was used to test for station effects on benthos abundance. Station 1 benthos density was significantly lower ($\alpha = 0.01$) than that at any of the other sites but no differences were detected between the remaining stations. Low benthos density at Station 1 can be related to the anoxia that characterized this site.

Chironomid Distribution, Life History and Production

Procladius bellus was present at all but three of the 95 sites sampled, while *Chironomus plumosus* was collected from all 95 sites (Figure 4). *Microcricotopus* and *Glyptotendipes* were much more restricted in their distribution in Big Bear Lake. *Microcricotopus* was never abundant at the monthly study sites. It's distribution was resticted more to the littoral zone of the lake. The March 1977 synoptic illustrates this distributional pattern (Figure 4). *Microcricotopus* was virtually absent from the main body of the lake, being abundant only toward the heads of the embayments and at the shallow east end of the lake. By the June synoptic, most *Microcricotopus* had emerged and its benthic population was uniformly low or absent. *Glytotendipes* was abundant at a few locations in June (maximum density ∾ 3200 • m^{-2}) but was virtually absent from the synoptic sites in March, September, and December.

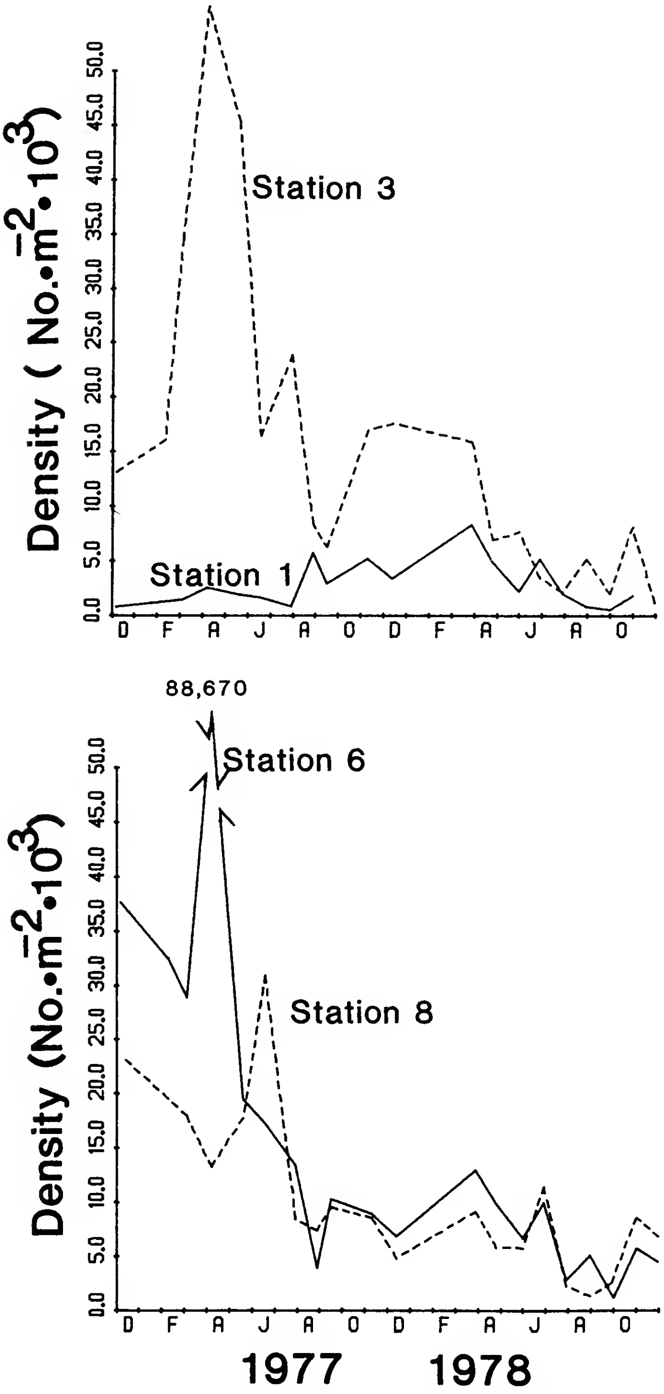

FIGURE 3. Density of Benthic macroinvertebrates at Big Bear Lake study sites, December 1976–November 1978.

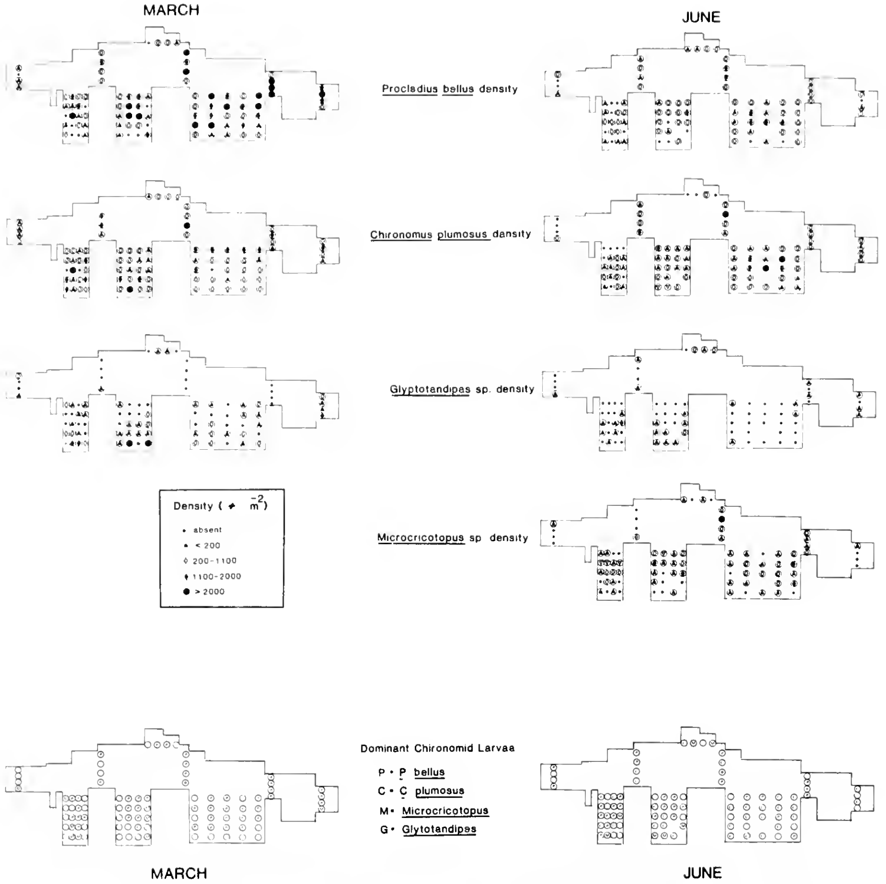

FIGURE 4. Distribution and dominance of chironomid larvae at Big Bear Lake synoptic study sites, March and June 1977.

P. bellus was generally the most abundant chironomid at the main study sites but *C. plumosus,* being much larger, generally dominated the standing crop (Figure 5). *P. bellus* was generally the most abundant larvae at the midlake sites and at the lakeward bay sites during the synoptic studies (Figure 4). *C. plumosus* was the most abundant larvae at most other synoptic sites and dominated chironomid standing crop at almost all synoptic sites. *P. bellus* density ranged up to $\simeq$ 4550 larvae • m^{-2} in the March synoptic and to $\simeq$ 1660 larvae in the June synoptic while *C. plumosus* density ranged up to $\simeq$ 2700 and $\simeq$ 2200 larvae • m^{-2} in the March and June synoptic, respectively. Chironomid densities were uniformly low at all synoptic sites in September and December 1977.

P. bellus density and standing crop peaked in the spring in both 1977 and 1978: 4850 • m^{-2} (1.22 g AFDW • m^{-2}) in 1977 and ∾ 1450 • m^{-2} (0.4 g AFDW • m^{-2}) in 1978 (Figure 5). The pattern of *P. bellus* seasonal abundance (Figure 5) reflects inefficient sampling of early instars. The mesh size used did not effectively retain early instars. Abundance would be expected to peak somewhat earlier than illustrated in Figure 5; i.e., at the time of peak recruitment. The *P. bellus* population minimum occurred in September 1977; ∾ 285 larvae • m^{-2} (0.04 g AFDW • m^{-2}). *P. bellus* was absent from the midwater sites from August through September 1978.

C. plumosus population maxima occurred somewhat earlier than that of *P. bellus* in each year of study. In 1977, *C. plumosus* density and standing crop peaked in February at ∾ 1835 larvae • m^{-2} (5.52 g AFDW • m^{-2}). Unsafe ice conditions made it impossible to collect benthos in January and February 1978. *C. plumosus* density and standing crop recorded in March 1978, ∾ 730 larvae • m^{-2} and 3.22 g AFDW • m^{-2}, respectively, were the highest values recorded for the *C. plumosus* population in 1978. *C. plumosus* was absent from benthic samples collected from July through September 1978. The 1977 *C. plumosus* population minima occurred in June (standing crop) and November (density).

Chironomid abundance was significantly lower ($\alpha = 0.002$) at Station 1 than at any of the other sites. *P. bellus* density did not exceed 500 • m^{-2} at Station 1 but exceeded 3000 • m^{-2} at the other sites. *C. plumosus* was rarely collected at Station 1; only 13 larvae were collected at this site during the entire study. These station differences are attributable, in part, to the extensive periods of hypolimnetic anoxia that develop at Station 1 each year. Release of toxic substances during anoxia may also occur, further limiting the suitability of Station 1 as benthos habitat.

The effect of lake level on chironomid abundance was readily apparent at Stations 3, 6, and 8. Both *P. bellus* and *C. plumosus* abundance was significantly greater ($\alpha = 0.002$) in 1977 than in 1978. There was no significant difference in the 1977 and 1978 abundance of these chironomid larvae at Station 1. While Big Bear Lake water levels were low in 1977, the lake mixed to the bottom at Stations 3, 6, and 8, maintaining habitat for these larvae. High water levels in 1978 allowed the water column to stratify and anoxia to develop at each of these sites. The effect on annual production was readily apparent. Annual production of *P. bellus* was estimated as 2.94 g AFDW • m^{-2} • yr^{-1} in 1977 but only 0.83 g AFDW • m^{-2} • yr^{-1} in 1978, a decrease of 72% (Table 2). Annual turnover ($P/\overline{B}$, where P = production and $\overline{B}$ = mean biomass) was fairly constant ($\simeq$ 6 in 1977 and $\simeq$ 7 in 1978). *C. plumosus* production was reduced from 3.85 g AFDW • m^{-2} • yr^{-1} in 1977 to 1.38 g AFDW • m^{-2} • yr^{-1} in 1978 (Table 2).

TABLE 2. Annual Production of Chironomid Larvae, Station 6, Big Bear Lake, California, 1977–1978. (Based on size frequency method).

Chironomid species	*Production g • AFDW • m^{-2}* 1977	1978
Procladius bellus	2.94	0.83
Chironomus plumosus	3.85	1.38

P. bellus has a bivoltine life cycle in Big Bear Lake with emergence in the spring and fall. Their size frequency distribution indicated recruitment in June and September (Figure 6). Pupae occurred in the benthos in April, May, and November 1977, and in March–May 1978. The fall emergence in 1978 was very small as *P. bellus* was absent from the study sites from July through September (Figure 5). *Procladius* have been shown to be bivoltine in warm, shallow lakes (Mundie 1957) but may have more than two generations in the littoral zone (Borutzky 1939).

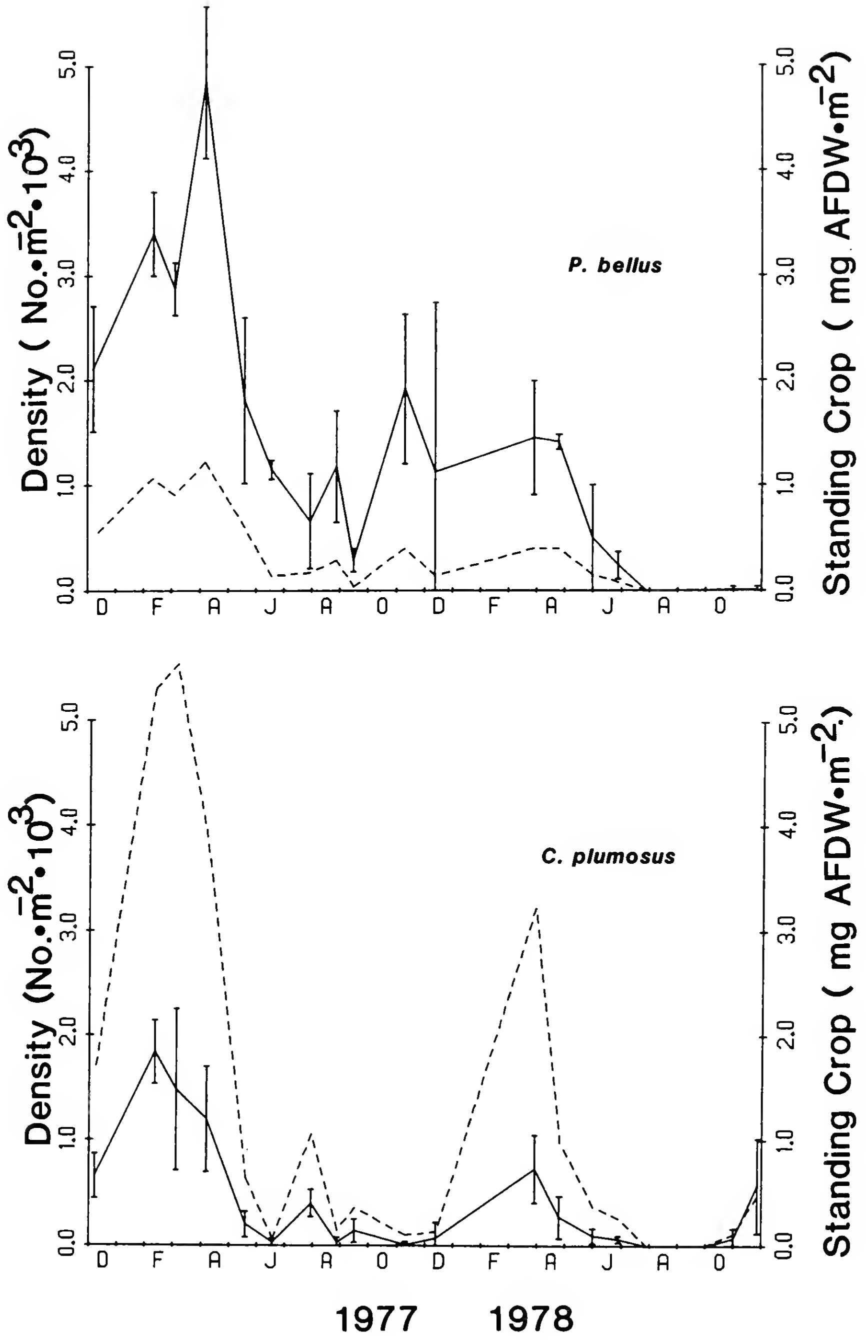

FIGURE 5. Abundance (solid line) and standing crop (dashed line) of *P. bellus* and *C. plumosus* at Station 6, Big Bear Lake, California, December 1976–November 1978. Vertical lines represent standard deviation about the mean density.

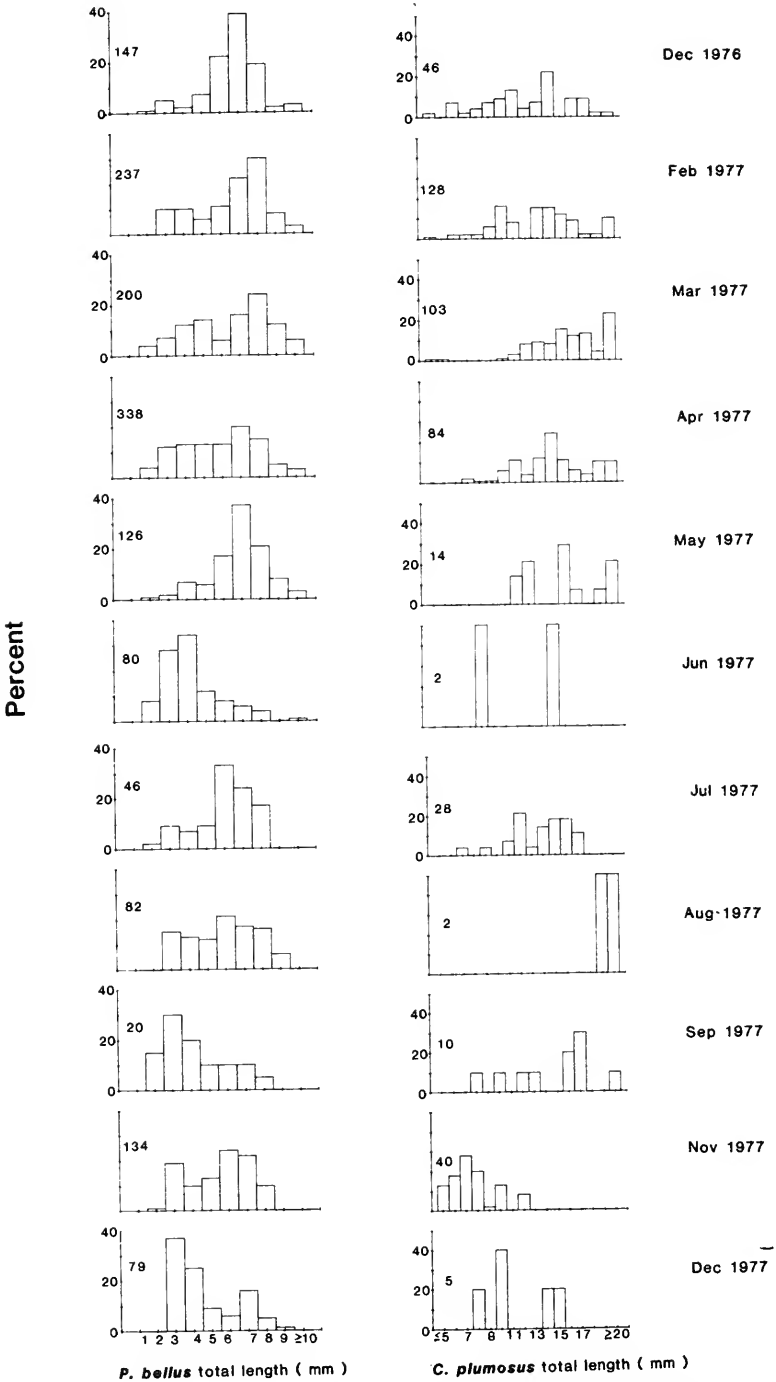

FIGURE 6. Size frequency distribution of *P. bellus* and *C. plumosus* collected at Station 6, Big Bear Lake, California, December 1976–November 1977. Numbers above each histogram represent number of larvae measured.

C. plumosus is one of the most characteristic inhabitants of the benthos of eutrophic lakes. It is generally considered the chironomid larvae most tolerant of anoxic conditions (Mundie 1957) because of its use of hemoglobin to bind oxygen. *C. plumosus* is univoltine in Big Bear Lake, emerging in May–June of each year (Figure 6). *C. plumosus* may have multi-generations in the shallow littoral zone of some lakes but only one generation per year at deeper sites (Maitland *et al.* 1972). The recruitment evidenced in the fall at Big Bear Lake may be the result of delayed hatching from eggs laid in spring–early summer or may represent young from a fall emergence from the littoral zone of the lake.

Lake Management, Fisheries and Benthos

The gamefish populations of Big Bear Lake prey heavily on benthic macroinvertebrates, particularly in the spring when chironomid larvae are abundant (Siegfried, Pickard, and Herrgesell 1979). During the spring of 1978, chironomid larvae represented >25% of the prey biomass consumed by rainbow trout, *Salmo gairdneri.* Chironomid larvae were the principal food of channel catfish, *Ictalurus punctatus*, and were important in the diets of bluegill, *Lepomis macrochirus,* and pumpkinseed, *L. gibbosus,* in the spring. Centrarchids consumed chironomid larvae throughout the year, obtaining them in the littoral zone of Big Bear Lake. Rainbow trout and channel catfish inhabit the deeper, pelagic waters of the lake where chironomid larvae were unavailable during stratification. The trout and catfish diets reflected this shift in prey availability (Siegfried *et al.* 1979) The biomass of prey consumed by rainbow trout and channel catfish in Big Bear Lake was significantly lower during stratification than during the spring. Although other factors are important, the lack of chironomid prey at the midlake sites in Big Bear Lake may be an important factor in the condition of these fish during stratification.

The benthic fauna of Big Bear Lake is characteristic of eutrophic conditions, i.e., generally tolerant of low dissolved oxygen concentrations. However, in spite of this tolerance, the chironomid fauna is absent from the midlake sites of Big Bear Lake during stratification. Both *P. bellus* and *C. plumosus* can tolerate prolonged periods of low dissolved oxygen concentrations (Curry 1965) yet quickly disappeared from the study sites as the dissolved oxygen was depleted from the hypolimnetic waters. This suggests that some other factors may be important in displacing the chironomids from these sites. During anoxia many substances, e.g., iron and manganese, normally bound to the sediments, may be released into the overlaying waters. Very low concentrations of these substances may be toxic to chironomid larvae (Curry 1965). Substances released during anerobic decomposition may also have toxic effects, e.g. hydrogen sulfide and ammonia. Ammonia concentrations in excess of 5 $mg \bullet l^{-1}$ were recorded in hypolimnetic waters during stratification. Although only a small percentage of this ammonia would be in the un-ionized (toxic) form, it may present a threat to the benthic macroinvertebrates. The European Inland Advisory Commission has set a concentration of 0.025 $mg \bullet l^{-1}$ un-ionized ammonia as the maximum allowable level to protect all life stages of fish. Calculation of un-ionized ammonia concentrations (Morgan and Turner 1977) indicate that this value was greatly exceeded in the hypolimnion during much of the stratified period. Ammonia toxicity may be an important factor regulating benthos community abundance in Big Bear Lake.

One of Big Bear Municipal Water District's (BBMWD) management goals for Big Bear Lake is the stabilization of water levels. Maintenance of high water levels would make the low hypolimnetic oxygen concentrations, characteristic of all study sites in 1978, typical of the lake each year and thus maintain low midlake benthos populations. An injection air system was installed at Big Bear Lake in the summer of 1981. A limited monitoring effort by BBMWD personnel indicates that the aeration system was successful in maintaining dissolved oxygen in the hypolimnion (BBMWD unpubl. data). Limited sampling during 1981 suggests an increase in both chironomid larvae and oligochaete abundance at the midlake sites after aeration. Nematode abundance increased dramatically following aeration. This is in general agreement with the effects of aeration on the benthic community of El Capitan Reservoir (Inland Fisheries Branch 1970). Hypolimnetic aeration will be an important management tool for maintaining benthos populations as well as for improving general water quality conditions.

A continuing management objective at Big Bear Lake has been the control of macrophyte growth. Macrophyte growth is considered a serious problem at Big Bear Lake, necessitating frequent harvesting to maintain navigable marinas. BBMWD tested the herbicide, dichlobenil (Casoron ^{r}), for control of macrophytes at Big Bear Lake. Dichlobenil was very effective in controlling macrophyte growth; the treatment created an area of little or no macrophyte growth that was surrounded by dense macrophyte beds. During the spring a fairly diverse benthic assemblage was present, with oligochaetes, chironomid larvae, gastropods, amphipods, and odonata naiads present (Figure 7), i.e. a typical assemblage of littoral macrobenthos. By July the only macroinvertebrates collected at the treatment site were oligochaetes (Figure 7). Several littoral sites were sampled throughout 1977 and one, in Metcalf Bay, was also sampled from June–November 1978. Chironomids were important components of the benthic fauna on each study date at these littoral sites, e.g. Station 4 (Figure 7). Gastropods, odonate naiads, amphipods, and mites were collected throughout the year at many of these littoral sites (Siegfried *et al.* 1978). Wilson and Bond (1969) reported dichlobenil to immobilize insect larvae at concentrations as low as 2.8 $mg \bullet l^{-1}$. The recommended rate of application of dichlobenil would result in water column concentrations of $\simeq 1.1\ mg \bullet l^{-1}$. However, dichlobenil is formulated to sink and form a layer at the mud-water interface and actual concentrations in the benthic zone would be considerably higher than that calculated as a water column mean (Wilson and Bond 1969).

The absence of insect larvae from the dichlobenil treatment area is not necessarily indicative of toxic effects. The elimination of macrophytes decrease habitat diversity and shelter for macroinvertebrates. The lack of shelter may make macroinvertebrates in this area easy prey for fish. Further controlled experiments are necessary to determine the impacts of macrophyte control by herbicide application in Big Bear Lake.

Hypolimnetic aeration and macrophyte control are the primary management strategies for combating the symptoms of eutrophication at Big Bear Lake. The general shallowness of the lake in combination with high nutrient content and watershed development precludes any significant change in trophic state. However, symptomatic treatments, such as aeration, can enhance the resource potential of Big Bear Lake.

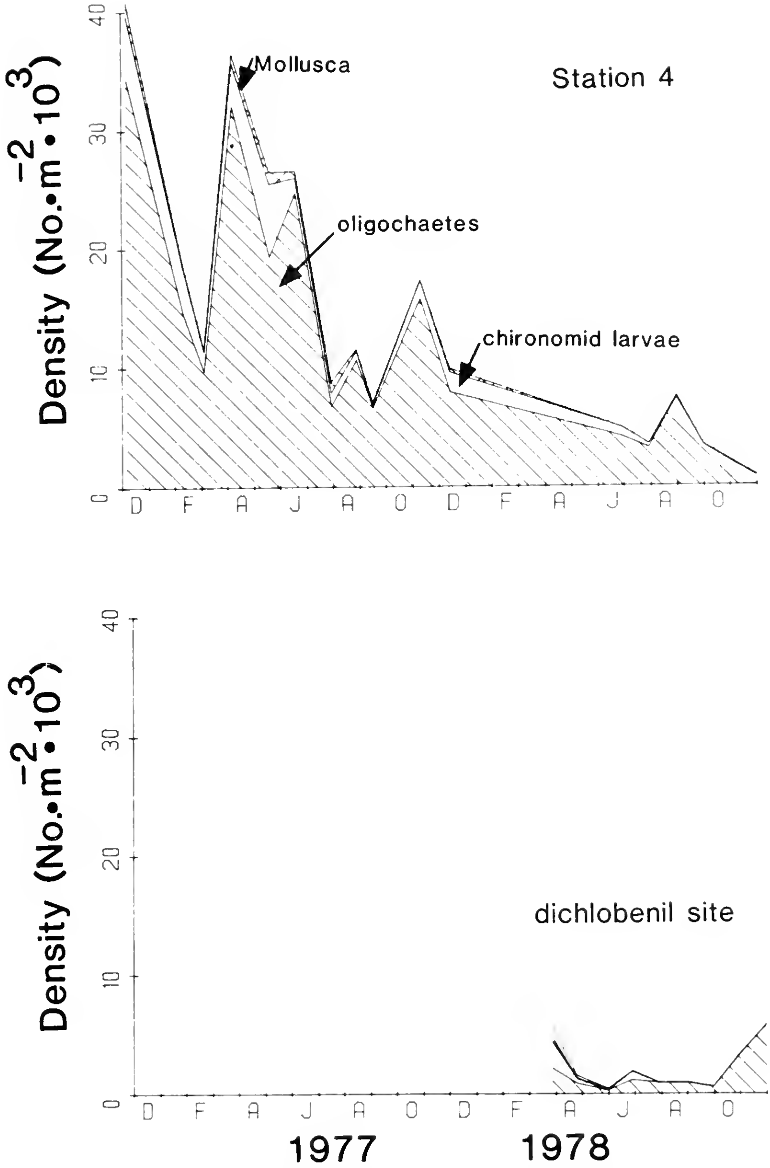

FIGURE 7. Abundance and composition of benthos collected from dichlobenil treatment area and Station 4, Metcalf Bay, December 1976–November 1978.

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DISTRIBUTION AND TAXONOMIC AFFINITIES OF MULE DEER, *ODOCOILEUS HEMIONUS,* FROM ANZA-BORREGO DESERT STATE PARK, CALIFORNIA [1]

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The distribution and taxonomic status of mule deer, *Odocoileus hemionus,* from Anza-Borrego Desert State Park, California and vicinity are re-evaluated using cranial morphometrics and field observations. Evidence is presented suggesting deer from this broad, arid region are intergrades between southern mule deer and burro deer. The distribution of these intergrades is delineated with respect to the ranges of southern mule deer and burro deer. The possible origin of this population is discussed in an evolutionary context, and those factors which may contribute to intergradation between burro deer and southern mule deer are explored.

INTRODUCTION

The distribution and taxonomy of the subspecies of mule deer, *Odocoileus hemionus,* in California have been detailed by numerous authors (Hall 1927; Grinell 1933; Sheldon 1933; Dixon 1934; Cowan 1936, 1956; Longhurst, Leopold, and Dasmann 1952; Hall and Kelson 1959; Hoffmeister 1962; and Dasmann 1965). Their range maps show either a conspicuous absence of deer from a broad, arid corridor in eastern San Diego and western Imperial counties, or suggest that southern mule deer, *O. h. fuliginatus,* inhabit this region. Within this area lies Anza-Borrego Desert State Park, encompassing over 200,000 ha and spanning portions of San Diego, Riverside, and Imperial counties. Coastal and montane areas west of this region are inhabited by southern mule deer, whereas burro deer, *O. h. eremicus,* occupy desert regions to the east. Hoffmeister (1962) synonymized *eremicus* with *crooki,* but his rationale for this was not compelling; thus we retain Cowan's (1936, 1956) designation of *eremicus* for burro deer. Burro deer are distinguished from southern mule deer by their larger body size, ears, and rump patch, and by the darker pelage and black dorsal stripe of southern mule deer (Hall 1927, McLean 1930, Longhurst and Chattin 1941, and Cowan 1956). Cowan (1936, 1956) and Longhurst and Chattin (1941) provide additional characteristics which allow differentiation between these subspecies.

While conducting surveys of springs in the State Park and its vicinity, we observed numerous deer that did not conform to morphological descriptions of southern mule deer or burro deer provided by Cowan (1936, 1956) and Longhurst and Chattin (1941). The purpose of this paper is to provide information

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on the distribution of these desert deer and to comment on their probable taxonomic affinities.

METHODS

Four skulls of adult male deer from the State Park were examined. One skull (ABDSP 662-I-143) was recovered from Chuckwalla Wash, San Diego County. The other skulls (ABDSP 662-X-56, 662-X-57, and 662-X-71) were found within the Park, but more precise locality data were unavailable. Cranial measurements were recorded in the manner described by Cowan (1936).

Locality data, written physical descriptions, and photographs of deer observed by the authors were collected from June 1976 through August 1979. Additionally, we made field observations of southern mule deer in the Cuyamaca Mountains of San Diego County and burro deer in eastern Imperial County to compare with deer seen in the State Park.

RESULTS

Deer distinct in appearance from southern mule deer and burro deer were observed at 13 localities in and around the State Park (Figure 1). These deer possessed ears, rump patches, and bodies that appeared intermediate in size between the smaller southern mule deer and larger burro deer. The pelage was lighter than the sooty-colored coats of southern mule deer, and the antlers were wide and diverging like those of burro deer (Longhurst and Chattin 1941:3), but the antlers of State Park deer appeared smaller in overall size.

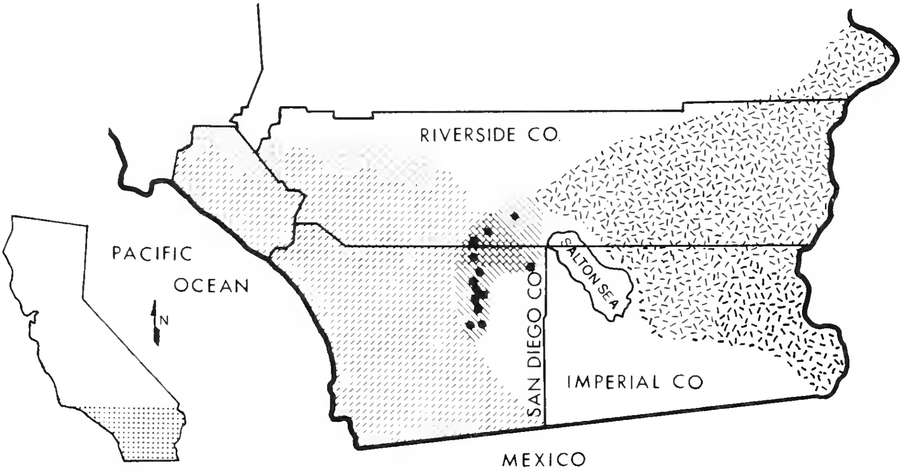

FIGURE 1. Probable zone of intergradation (continuous diagonal lines) between the published ranges of southern mule deer (broken diagonal lines) and burro deer (hatching). Dots indicate sightings of mule deer from Anza-Borrego Desert State Park, California.

Those characteristics that Cowan (1936) suggested were the most diagnostic for differentiating subspecies of mule deer were used to compare deer skulls from the State Park with those of southern mule deer and burro deer. Cranial measurements of skulls from the Park (Table 1) fell between those for southern mule deer and burro deer in eight of ten cranial characteristics (Figure 2). A Friedman two-way analysis of variance (Siegel 1956) showed this pattern to be highly significant ($\underline{X}r^2 = 15.7$, $P < 0.001$, 2 d.f.).

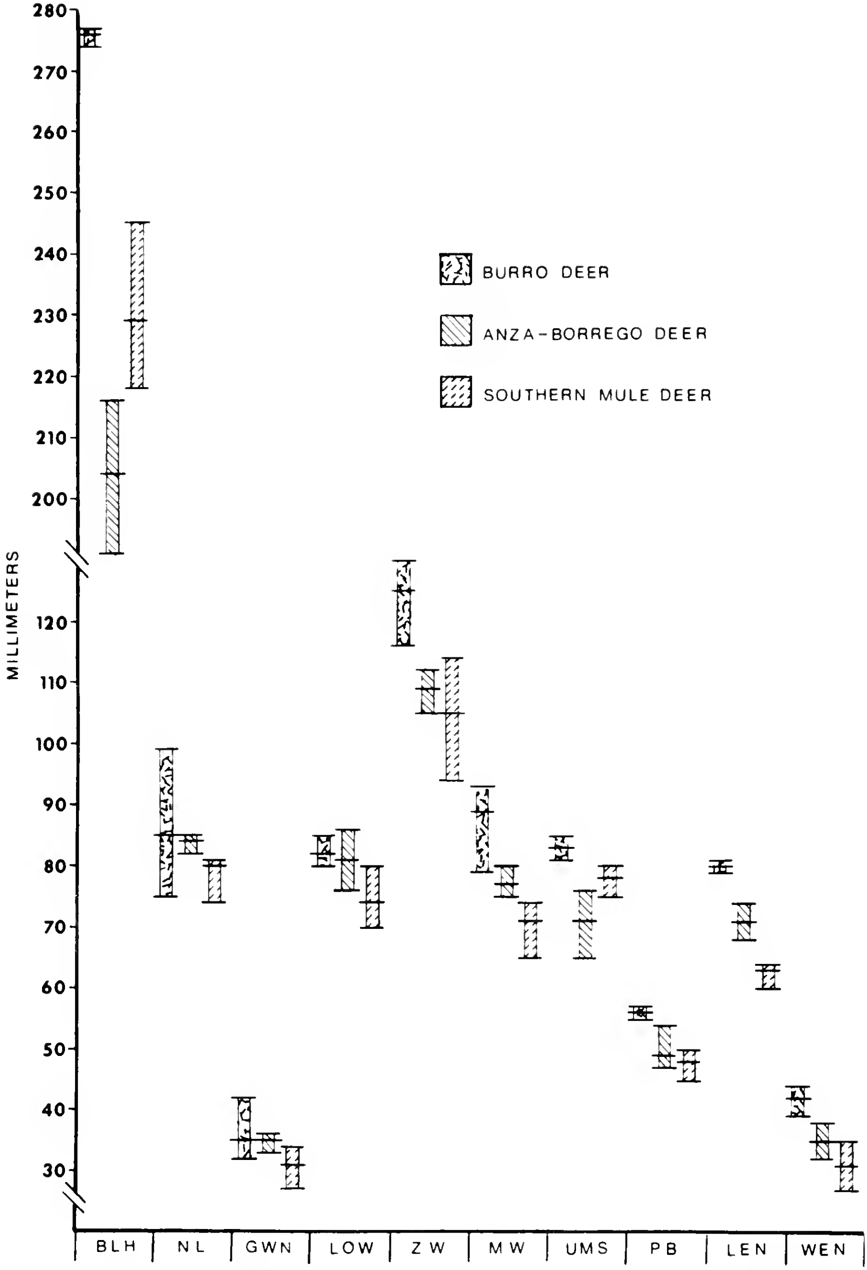

FIGURE 2. Comparisons of means and ranges for selected measurements for mule deer from Anza-Borrego Desert State Park, burro deer, and southern mule deer. Data for southern mule deer and burro deer are from Cowan (1936). BLH = Basilar length of Hensel; NL = Nasal length; GWN = Greatest width of nasals; LOW = Least orbital width; ZW = Zygomatic width; MW = Mastoid width; PB = Palatal breadth; WEN = Width external nares; LEN = Length external nares; UMS = Length of upper molar series.

Ninety ratios between paired combinations of 10 cranial measurements also were considered. Forty-seven percent of skull measurement ratios from the Park were closer to those of southern mule deer, 47% were closer to burro deer, and 6% were midway between the two subspecies.

TABLE 1. Skull Measurements of Adult (2 yrs +) Male Deer from Anza-Borrego Desert State Park, California

MEASUREMENT (mm)	*MEAN*	*SD*	*RANGE*	*N*
Basilar length of hensel	204	10.3	191–216	3
Nasal length	84	1.6	82–85	2
Greatest width of nasals	35	1.3	33–36	3
Least width of nasals	24	1.6	22–26	3
Least orbital width	81	3.8	76–86	4
Zygomatic width	109	2.6	105–112	4
Mastoid width	77	2.1	75–80	4
Maxillary width	84	2.9	81–88	3
Palatal breadth	49	3.3	47–54	3
Post-palatal width	29	1.0	28–30	2
Width external nares	35	2.5	32–38	3
Elevation of rostrum	50	1.6	48–51	2
Length of external nares	71	2.5	68–74	3
Upper molar series	71	4.5	65–76	3

DISCUSSION

Qualitative differences in the appearance of deer in the field, intermediate cranial measurements, and medial ratios derived from these measures suggest that deer from Anza-Borrego Desert State Park and vicinity cannot be assigned confidently to either *O. h. fuliginatus* or *O. h. eremicus.* Subspeciation in the corridor between the ranges of southern mule deer and burro deer would require substantial barriers to gene flow and habitats dissimilar enough for natural selection to favor the evolution of differing morphological adaptations; no evidence for these exist. Moreover, the overlap in the ranges of many skull measurements (Figure 2) suggests much of the variation is clinal, and that total genetic isolation did not occur. The most tenable hypothesis is that deer from the region of the State Park are intergrades between southern mule deer and burro deer.

Cowan (1936) speculated that burro deer and southern mule deer may interbreed in eastern San Diego County; however, he offered no evidence to substantiate this contention and failed to indicate the areas on his range map. Longhurst and Chattin (1941) suggested the possibility of intergradation between *eremicus* and other subspecies of deer along zones of contact, but they did not eleborate on the locations of these areas. Similarly, Hoffmeister (1962) noted that *crooki* (= *eremicus*) interbred with *fuliginatus,* but his range map clearly shows their distributions as noncontiguous. Hall and Kelson (1959) closed the gap between the distribution of burro deer and southern mule deer but provided no rationale for depicting the ranges of these subspecies as being contiguous. Finally, Cowan (1936) suggested that the Santa Rosa Mountains, at the Riverside-San Diego county line, were occupied by southern mule deer. Hall's (1927) range maps, however, indicate that burrow deer inhabit the southern terminus of that range, which is within the Park. Field observations suggest that some deer from the southern Santa Rosa Mountains are similar in appearance to others we encountered in the vicinity of the State Park, and we hypothesize that these deer may be intergrades, also.

The area of intergradation between southern mule deer and burro deer is extensive (Figure 1), and depicting their ranges as contiguous over so large an area is biologically unrealistic. Thus, we suggest that future range maps of mule deer subspecies show the area defined in Figure 1 as a zone of probable southern mule deer-burro deer intergradation. Obviously, the data presented in Figure 1 are incomplete, because we have limited information for western Imperial County. We hope, however, that this paper will stimulate further investigations into the distribution and taxonomic status of deer from the deserts of southern California.

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NOTES

DIPODOMYS CALIFORNICUS IN SIERRA VALLEY, PLUMAS COUNTY, CALIFORNIA

On 13 August 1979 the authors salvaged a dead California kangaroo rat, *Dipodomys californicus* (formerly *D. heermanni californicus,* see Patton 1976), on Highway A23, 12.6 km south of Beckwourth, a few metres from the Plumas-Sierra county border just within Plumas County, California. This species is noted to occur on the eastern side of the Sierra Nevada south to Honey Lake, Lassen County, California (Hall 1981, Grinnell 1922) and in northeastern California, Fort Bidwell area, Modoc County (Hubbard 1961). We know of no other data concerning more southerly records of its occurence east of the Sierra Nevada. We report here the first record of its presence in Sierra Valley, Plumas County, California.

The specimen was found in an area of sagebrush bordering pine-fir-sagebrush as described by California Department of Water Resources (1973). The specimen is deposited at the California Academy of Sciences (CAS 21686), San Francisco. The measurements (in mm) are: total length 312; tail 182; hindfoot 44; ear 17; greatest length of skull 37.8; breadth across bullae 24.2; spread of maxillary arch 21.35; greatest length of nasals 14.2; width of rostrum 4.6; width of maxillary arch at middle 5.3.

We attempted to trap this species near the location of discovery (1840 trap nights), but were unsuccessful. Extensive sampling is necessary to determine whether the present specimen is from an isolated population or from a population widely distributed in northeastern California and adjacent Nevada.

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AGE AND GROWTH OF FLORIDA LARGEMOUTH BASS, *MICROPTERUS SALMOIDES FLORIDANUS*, IN HIDDEN VALLEY RESERVOIR, LAKE COUNTY, CALIFORNIA

INTRODUCTION

Improved angling attributed to Florida largemouth bass introductions into Southern California (Bottroff and Lembeck 1978) has prompted their transfer to lakes and reservoirs at more nothern latitudes (Pelzman 1980). Desirable fishery characteristics exhibited by Florida bass at southern latitudes (when compared with northern bass, *M. s. salmoides*) include: (i) higher growth rate; (ii) greater longevity; and (iii) greater resistance to excessive harvest by anglers. These characteristics have resulted in an increase in abundance of trophy-sized bass in southern waters.

Hidden Valley Lake, Lake County, is a 43-ha impoundment at an elevation of 305m. It was devoid of bass until 1969 when Florida largemouth bass were introduced. This provided an opportunity to determine if growth and longevity of Florida bass would be duplicated at a more northern latitude. Additional evidence of superior performance by Florida bass was also obtained from Clear Lake, Lake County and Lake Chabot, Alameda County where Florida bass were stocked over self-sustainting populations of the northern form.

METHODS

Growth histories of bass were determined by counting annuli on scales taken near the tip of the left pectoral fin. Scales were cleaned, dried, and mounted on microscope slides and magnified 50x with a Bausch and Lomb micro-projector. The main criterion used for annulus identification was "crossing over" of the circuli in the lateral fields. Bass were collected by electrofishing in January and March 1981. A total of 58 bass was successfully aged. Back calculations of fork length in millimetres at each age were made using methods described by Tesch (1970). Data on the incidence of exceptionally large specimens were provided by the lake recreational manager, anglers, or electrofishing.

RESULTS AND DISCUSSION

Florida bass at Hidden Valley Reservoir reached mean calculated fork lengths of 176, 281, 361, 427, 478, 519, 559, 580, and 616 mm at ages I through IX, respectively. This growth rate exceeds that of northern bass in California at similar latitudes (Tharratt 1966, Schultze and Vanicek 1974, Emig 1976) and is similar to Florida bass growth recorded at El Capitan Reservoir, San Diego County (Bottroff and Lembeck 1978).

Angler and electrofishing catches of Florida bass at Hidden Valley Reservoir show that individual fish can attain large adult size similar to that recorded in San Diego County. From the original April 1969 plant of 25 fin-clipped bass ranging from 12 to 35 cm total length (estimated), I have inspected three weighing in excess of 4.5 kg. An additional four unmarked bass exceeding 4.5 kg have been reported, including the lake record bass weighing 6.4 kg (D. Whiteside, pers. commun.).

Florida bass introductions into other California waters have likewise produced large specimens. On 22 July 1980, the Clear Lake record largemouth bass was caught. It weighed 5.2 kg and bore a right ventral mark indicating it was from the original plant of Florida bass made on 9 April 1969. During May 1980, a largemouth bass weighing 7.9 kg was found dead at Lake Chabot, Alameda County (K. Burger, Water Management Specialist, E. Bay Reg. Park Dist., pers. commun.). This may be the largest largemouth bass ever documented from northern California waters. Analysis of muscle tissue by electrophoresis confirmed that the Clear Lake fish was pure Florida strain and the Lake Chabot fish possessed Florida alleles (R. J. Pelzman, Fishery Biologist, Calif. Dept. of Fish Game, pers. commun.). Twenty-five Florida bass of unknown size had been stocked into Lake Chabot during September 1971.

It is evident that Florida bass grow rapidly and attain trophy size in waters well north of those previously studied in California. Moreover, their growth rates exceed those of northern bass in the same or similar waters, suggesting that their growth is genetically controlled. On this basis, it appears Florida largemouth bass would be a desirable addition to the warmwater fish fauna of selected reservoirs in central and northern California. However, other attributes of Florida bass, such as low vulnerability to angling, their impact on forage species and other warmwater gamefish, and reported low tolerance to colder water temperatures should be considered when selecting additional waters.

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THREE SPECIES OF SEA TURTLES COLLECTED FROM NORTHERN CALIFORNIA

Marine turtles typically inhabit tropical and subtropical seas (Stebbins 1966) and documented sightings along the California coast are uncommon. Since 1969 a green turtle, *Chelonia mydas,* a Pacific ridley, *Lepidochelys olivacea,* and a leatherback, *Dermochleys coriacea,* have been collected from northern California and deposited in the Vertebrate Museum, Humboldt State University (HSU), Arcata, California. This report summarizes data obtained from these specimens and documents their occurrence in California.

CHELONIA MYDAS

Historically, green turtles were common in San Diego Bay, California (Van Denburgh 1922, Stebbins 1966) but now appear to be limited to a single channel in the southern part of the bay (Hubbs 1977). Dubious records of this species from San Francisco also exist (Stebbins 1954). A female *C. mydas* (HSU 516) washed ashore alive at the mouth of Redwood Creek, Humboldt County, on 14 December 1969. This specimen weighed 28.8 kg; the carapace measured 64.2 cm in length and was 51.2 cm wide.

LEPIDOCHELYS OLIVACEA

The northernmost record for the Pacific ridley is Table Bluff, Humboldt County, California (Houck and Joseph 1958). Morejohn (1969) photographed and reported a Pacific ridley from Monterey Bay in 1967. In 1973 Hubbs (1977) observed a pair of Pacific ridleys copulating in the water off La Jolla, San Diego County. On 16 December 1981 a female Pacific ridley was found floating alive, but motionless, in the ocean near Trinidad, Humboldt County. This specimen (HSU 514) weighed 12.4 kg and had the following external measurements: total length, 59.0 cm; carapace length, 45.9 cm; maximum carapace width, 45.1 cm; head length, 11.1 cm; head width, 8.6 cm; tail length, 5.0 cm; length from cloaca to tip of tail, 2.4 cm. This is the fourth record of *L. olivacea* in the state.

DERMOCHELYS CORIACEA

Leatherback turtles generally inhabit tropical and subtropical waters; however, leatherbacks have been reported as far north as Sedgwick Bay, Queen Charlotte Island, British Columbia (Stebbins 1966) and sightings along the California coast are not exceptionally rare. Two *D. coriacea* were caught off Santa Barbara, one in 1901 and the other in 1905; an additional specimen was collected near Pigeon Point, San Mateo County (Van Denburgh 1922). Van Denburgh (1922) also reported leatherbacks from Point Loma, although no specific documentation was provided. A leatherback was collected near San Diego in 1907 (Carr 1952). This specimen may have been the same specimen mentioned by Van Denburgh (1922). Myers (1933) recorded two specimens captured near San Francisco in 1929. Gary Friedrichsen and Timothy Osborne (pers. commun., both are trained zoologists) sighted a leatherback 27 km west of Humboldt Bay on 13 August 1977. Friedrichsen (pers. commun.) also sighted several leatherbacks 35 km WSW of Newport, Oregon between 15 and 30 July 1981. A dead female leatherback turtle (HSU 515) weighing approximately 210 kg washed ashore on Pebble Beach, Del Norte County, on 21 January 1981. The external measurements of this specimen are: total length, 168.0 cm; carapace length, 117.0 cm; maximum carapace width, 73.0 cm; head length, 23.5 cm; head width, 19.5 cm; length from cloaca to tip of tail, 8.5 cm.

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BIOCHEMICAL IDENTIFICATION OF A BLUEFIN TUNA ESTABLISHES A NEW CALIFORNIA SIZE RECORD

Large tunas are not commonly taken off the California coast and although stories exist of sightings of large yellowfin, *Thunnus albacares,* bluefin, *T. thynnus,* and bigeye, *T. obesus,* tunas, the current California size records for these species are 204 kg, 203 kg and 197 kg, respectively (Miller and Lea 1976). On 7 December 1981 a large tuna was captured in a shark gill net that was set 19.3 km south of Anacapa Island (lat 33°48.5′N, long 119°20.6′W). The fish was frozen after capture and sold 7 days later before a positive identification could be made. At the time of sale the fish's weight was determined in the round on a calibrated electronic scale to be 237 kg.

Few measurements were made of the tuna before it was butchered and sold. The total length was determined with a ruler to be approximately 198 cm. No photographs were taken of the fish, but the following physical description was offered by Mr. David Ptak, general manager of Chesapeake Fish Company: the fish was dark blue or black above and grayish white below, with some lighter vertical bars on the sides; the pectoral fins were short to moderate, reaching the 10th or 11th dorsal spine; the finlets were yellow; and the liver had a large central lobe with two lesser lobes, all of which were heavily striated on the ventral surface.

This description indicated that the large tuna, which would be a size record for any *Thunnus* species in California, was either a bluefin or bigeye tuna. Yellowfin tuna do not have striations of the ventral liver surface, whereas both bluefin and bigeye tuna may have completely striated ventral liver surfaces (Gibbs and Collette 1967). Bluefin and bigeye tuna can be separated on the basis of gillraker counts; however, gillraker counts were not made on the specimen and the head of the fish was not saved.

Due to a lack of meristic and morphometric data for the specimen, an alternate method of identification was employed. The relationships of scombrid fishes have been investigated with electrophoretic techniques and all *Thunnus* species can be distinguished on the basis of fixed allelic differences at one or more loci (Sharp and Pirages 1978). Bluefin and bigeye tuna can be separated by a fixed allelic difference at the glyceraldehyde-3-phosphate dehydrogenase (G-3-PDH) locus, an enzyme which occurs in high concentrations in tuna white muscle (Sharp and Pirages 1978). Fortunately, a small amount of the tuna's muscle had been maintained frozen by Mr. Ptak and was generously made available to the authors for an electrophoretic determination of its specific identity.

Samples of the tuna's muscle were run with samples of bigeye tuna and albacore, *T. alalunga,* muscle (frozen bluefin tuna muscle was not available for comparative purposes). Sample preparation and electrophoretic protocol followed the procedures of Graves and Rosenblatt (1980). A photograph of a gel slice stained for G-3-PDH activity is presented in Figure 1. The large tuna possessed an allele which had considerably slower anodal mobility than that of the bigeye tuna, yet slightly faster than that of the albacore. The mobility of the allele of the large tuna relative to the bigeye and albacore was similar to that reported for bluefin tuna by Sharp and Pirages (1978).

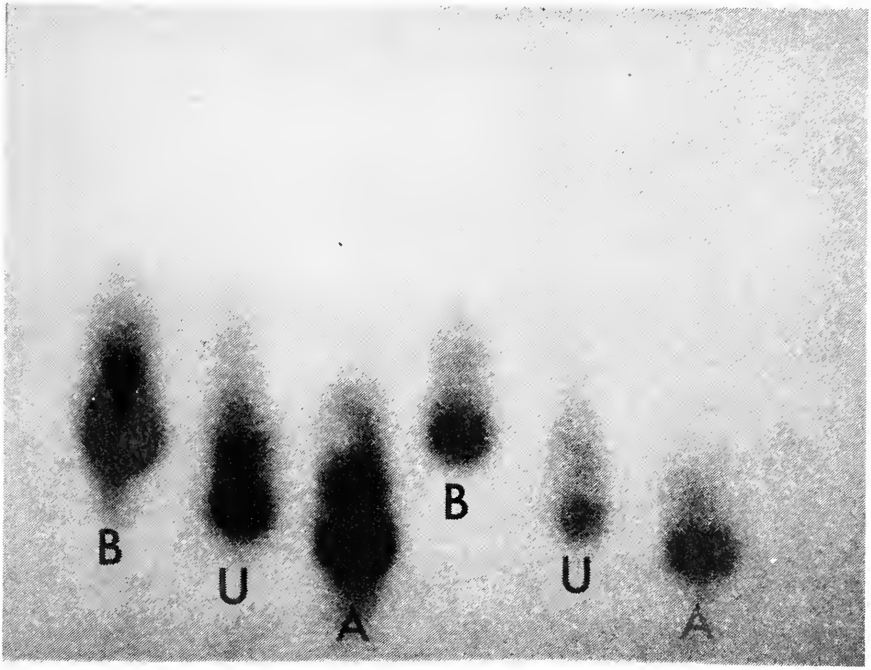

FIGURE 1. Electrophoretic mobilities of G-3-PDH alleles from three *Thunnus* species. Different stain intensities are the result of different tissue to grinding buffer ratios. B = bigeye tuna, U = unknown tuna (bluefin) and A = albacore tuna.

Although direct comparison with bluefin G-3-PDH was not possible, the large fish can be identified with confidence. The presence of striations on the liver of the specimen showed that it was not a yellowfin tuna. Because bigeye and bluefin tunas of the eastern Pacific are fixed for different alleles at the G-3-PDH locus, the lack of identity of the large tuna allele with that of the bigeye tuna demonstrated that the large tuna was not a bigeye tuna, and consequently must have been a bluefin. Furthermore, the mobility of the large tuna's G-3-PDH allele relative to that of the bigeye tuna and albacore was similar to that reported for bluefin tuna run under similar electrophoretic conditions (Sharp and Pirages 1978). On the basis of these results we conclude that the 237 kg tuna caught off Anacapa Island on 7 December 1981 was a bluefin tuna. This catch marks a substantial increase in the maximum size reported for this species in California waters.

Addendum: Since the paper has been edited a 180 kg bluefin tuna was speared off Guadalupe Island, Mexico during September 1982 and postively identified on the basis of morphological characters. In a direct electrophoretic comparison of muscle G-3-PDH, the mobilities of this bluefin and the 237 kg specimen were identical, providing positive evidence that the 237 kg fish was in fact a bluefin tuna.

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